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ANALYZING HORIZONTAL DISTANCES BETWEEN
WSR-88D THUNDERSTORM CENTROIDS AND
CLOUD-TO-GROUND LIGHTNING STRIKES

THESIS

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This has been by far the greatest challenge of my life. Now that it's over, as a final thought, there's only one more thing to say, "GO BIG RED!!!" --- Steve L. Renner

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ABSTRACT

On April 29, 1996, lightning struck the airfield at Hurlburt Field, FL, killing one Airmen and injuring ten others. This cloud-to-ground lightning strike hit eight minutes after a lightning advisory was canceled. At the time of the strike, thunderstorms were observed 7 to 10 miles north and south of the airfield. The incident raised questions about Air Force Weather Agency's lightning criteria. Soon after the incident, a Lightning Safety Review Panel was assembled to determine the adequacy of lightning advisories. One of the questions posed to the panel was "could an incident like Hurlburt happen again?" The review panel could not answer that question due to the lack of documented research on how far lightning can travel horizontally before striking the ground.

This thesis used the WSR-88D Algorithm Testing and Display System (WATADS) and the default parameters of the WATADS's Storm Cell Identification and Tracking (SCIT) Algorithm to identify thunderstorm centroids. Lightning strike data containing nearly 50,000 cloud-to-ground strikes was obtained through the National Climatic Data Center (NCDC). Horizontal distances were then computed between these storm centroids and cloud-to-ground lightning strikes.

This research discovered that average distances between thunderstorm centroids and lightning strikes vary with season and location. In addition, nearly 75% of all lightning strikes occurred within 10 nautical miles of thunderstorm centroids.

ANALYZING HORIZONTAL DISTANCES BETWEEN WSR-88D THUNDERSTORM CENTROIDS AND CLOUD-TO-GROUND LIGHTNING STRIKES

1. Introduction

a. Statement of the Problem

All Air Force and Army installations with active airfields have advisory criteria for lightning. These installations have different lighting criteria dependent on the type of aircraft supported at each specific airfield. These advisories range from lightning within 10 nautical miles from the airfield, 5 nautical miles, or 3 nautical miles depending on the particular airfield. An incident at Hurlburt Field, FL, raised questions about lightning advisory criteria. On, April 29, 1996, a routine "lightning within 3" advisory was issued at 0802L, after observers spotted a single lightning strike about 3 miles to the west of the base. This advisory was canceled at 0930L, giving the all clear signal for airfield activity, nearly 90 minutes after the last observed lightning strike. At 0938L, lighting struck, killing one Airmen and injuring 10 others. Another "lightning within 3" advisory was subsequently issued at 0940L. At the time of the strike, thunderstorms were observed 7 to 10 miles north and south of the airfield. The incident raised questions about Air Force Weather Agency's lightning criteria.

b. Importance of the research

Soon after the incident at Hurlburt Field, a Lightning Safety Review Panel was assembled to determine the adequacy of lightning advisories. One of the questions posed to the panel was "could an incident like Hurlburt happen again?" The review panel could

not answer that question due to the lack of documented research on how far lightning can travel horizontally before striking the ground. This problem affects all military and civilian employees on airfields. Knowledge of how far lightning can travel is a critical to the Air Force Weather Agency for recommending lightning advisory criteria. Additionally, horizontal distances will be analyzed in relation to the maximum dBZ to give forecasters and observers and idea of how far lightning can travel when a specific dBZ is observed on the WSR-88D.

2. Literature Review

a. Lightning

1) Background

Lightning is a high-current electric discharge caused by electric charge separation in thunderstorms. A flash is the total electric discharge, and lasts about half a second. The sequence of a cloud-to-ground lightning strike is shown in Figure 1 (Uman, 1984). The flash is composed of a number of discharge components. Each of these components consist of three to four high current pulses called strokes. Strokes typically last about a millisecond, and time between strokes is usually a few tens of milliseconds. The cloud brings to the earth a negative charge at a strength of tens of coulombs. Large numbers of electrons flow to the ground and the lightning stroke propagates up from the ground to the cloud along the path made by the charged stepped leader. This swift flow of electrons is the return stroke. The swift release of return stroke energy heats the leader channel to temperatures of 30,000K and produces a high pressure channel that expands and creates shock waves that develop thunder (Uman, 1987).

One mechanism for the electrification of thunderstorms is the transfer of charge between graupel and smaller ice particles. When graupel particles made in regions of strong updrafts collide with smaller ice particles, the polarity of the charge transfer in the collisions is dependent on the temperature and liquid water content. The -10°C to -20°C temperature range is often called the "charge reversal temperature." Below this temperature, a negative charge is transferred to graupel, and above the temperature, a

positive charge is transferred. This theory explains the positive charge region at upper levels of the thunderstorm (Houze, 1993).

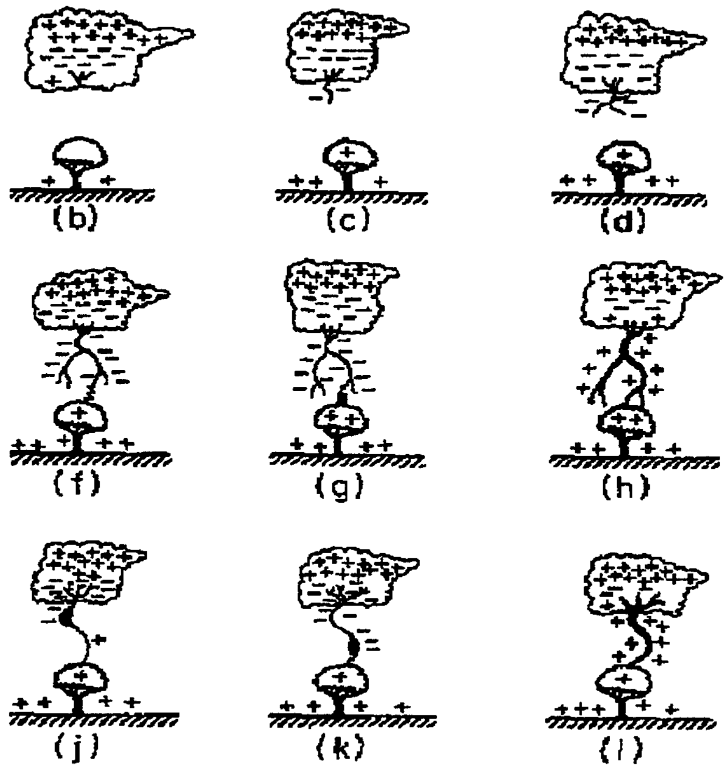

Figure 1 (Uman, 1984) The stepped leader initiates the first return stroke in a flash by propagating negative charge from the cloud to the ground in a sequence of distinct steps. The stepped leader is started by a local discharge between a small pocket of positive charge at the base of a thunderstorm and the lower part of the negatively charged region of the cloud (b). This discharge releases electrons that neutralize the small area of positive discharge, as in figure (c). Cloud to ground lightning is produced by a negatively charged step leader (e and f) moving downward from the cloud to the ground, especially on protruding objects. The attachment process occurs when upward moving discharges from the ground contact the downward moving step leader, and the edge of the leader is connected to the ground contact, as in figures (g and h). After the first stroke, subsequent strokes can occur along the same main channel, if there are additional electrons available to the top of the previous stroke. These additional electrons are called K or J streamers, which move upward from the top of the previous stroke to higher areas of the cloud (i). The negatively charged dart leader moves downward from the cloud along the first stroke channel, depositing additional electrons on the ground (j and k). The dart leader is followed by another visible return stroke (l) (Uman, 1984).

2) National Lightning Detection Network (NLDN)

The NDLN is a network that detects cloud to ground lightning flashes throughout the United States. GeoMet Data Services (GDS) currently operates the NDLN, and the

lightning data is available for government, military, and commercial use. The NDLN consists of a series of sensors that detect the lightning strikes by a wideband magnetic direction finding (DF) system. Every DF is composed of an orthogonal magnetic loop antenna, a flat plate antenna, and other electronics devices to process the incoming signals of the lightning flashes (Silver and Orville, 1995).

The DF sensors are constructed by Lightning Location and Protection (LPP) Incorporated. Three organizations control sensors throughout the United States: Bureau of Land Management (BLM), National Severe Storms Laboratory (NSSL), and GDS. The time of occurrence of a lightning strike is determined by the time of the peak radiation field of the first return lightning stroke. The time of a lightning strike is accurate to 0.1 ms for GDS sensors, approximately 5 ms for NSSL sensors, and within 5 ms for BLM sensors (Cummins and Hiscox, 1992). Location accuracy is within one-half a kilometer 50% of the time.

b. Weather Surveillance Radar-1988 Doppler (WSR-88D)

1) Background

The WSR-88D is the product of the Next Generation Weather Radar (NEXRAD) Program. About 150 units are operational in the United States. The total NEXRAD network furnishes nearly complete radar coverage of the entire country at an altitude of about 10,000 feet. About 15 additional radar systems are deployed in the Caribbean, Alaska, Hawaii, and at United States military installations overseas (Crum and Alberty, 1993b).

The WSR-88D system "collects, processes, and displays high-resolution and high accuracy of reflectivity, mean radial velocity, and spectrum width data" (Crum and Alberty, 1993b). With these existing resources, computer algorithms produce a great collection of meteorological and hydrological products critical for operational forecasters. The majority of algorithms come from two sources: WSR-88D algorithms, created by the applications branch of the WSR-88D Operational Support Facility (OSF), and NSSL algorithms, created by the NSSL. Most of these algorithms contain adaptable parameters that can be adjusted for a radar's specific geographical and climatological location. The WSR-88D system goes through a number of steps to process meteorological algorithms. This sequence originates from the Radar Data Acquisition (RDA), through the Radar Product Generator (RPG), to the Principal User Processor (PUP). The RDA contains the radar transmitter, receiver, antenna, and tower. The RPG is composed of computers and software to produce reflectivity, velocity, spectrum width, and many other useful products to forecasters such as composite reflectivity and storm total precipitation, etc. The RPG also prepares products for transmission to other locations. The PUP is the system where operational meteorologists read and analyze products from the RPG.

The WSR-88D consists of two operational modes, with each of these operational modes containing two volume coverage patterns (VCP). The VCP determines the number of elevation angles in a specified amount of time. Mode "A" is precipitation mode. Its two coverage patterns are called VCP 11 and 21. VCP 11 allows the WSR-88D fourteen elevation angles in five minutes, while VCP 21 allows nine elevation angles in six minutes. These coverage patterns provide excellent atmospheric surveillance in severe weather,

when more of the atmosphere can be analyzed in less time. Mode "B" is clear air mode. The coverage patterns in mode B are VCP 31 and 32. Both VCP 31 and 32 allow five elevations angles in ten minutes. These modes together provide a continuous surveillance of the atmosphere at each specific radar site.

The WSR-88D is comprised of approximately 11,500 adaptable parameters, broken down into three categories: meteorological, engineering, and operational (Crum and Alberty, 1993b). The meteorological adaptable parameters consist of roughly 400 variables used to enhance the performance of the radar's algorithms. Engineering adaptable parameters include about 600 variables that directly affect the radar's performance in meeting technical requirements. Examples of engineering algorithms are defining clutter filters and establishing communication links. Approximately 10,500 operational adaptable parameters directly impact the performance of the radar and indirectly affect computed algorithms. Product generation priority and product distribution control are examples of operational adaptable parameters (Crum and Alberty, 1993b).

The WSR-88D contains four levels of data. Level I data are located at the RDA. Data contained in Level I includes information on the analog and time domain output of the receiver, synchronization, calibration, date, time, antenna position, and radar status. Level I data is not permanently archived. Level II data includes digital base data output produced by the radar's signal processor in polar format at the full spatial and temporal resolution of the WSR-88D (Farris, 1997). Level II data contains ALL reflectivity, mean radial velocity, spectrum width, and system information such as date, time, operational

mode, and antenna position. Once the RDA has compiled Level II information, the WSR-88D processes the data and computes meteorological and hydrological algorithms. Level II data are stored on an 8 mm tapes and archived at the National Climatic Data Center (NCDC). The Level III data interface are located at the RPG. The products available from Level III data is defined in FMH-11, part A. Level III data are archived on optical disk and stored at NCDC, and are only a subset of data available in Level II format. The Level IV interface is located at the PUP. Any information available at the PUP may be stored at the discretion of the PUP operator. Level IV data are generally for local use, and are not stored at NCDC.

Level II data can be played back through any WSR-88D radar, or other computer systems with the appropriate software. In turn, researchers can use the Level II data to construct meteorological algorithms, improve current algorithms, or adjust adaptable parameters of meteorological algorithms for a specific geographical and climatological location. In addition, researchers use Level II data to devise and improve training methods for the WSR-88D. Since Level II data can be used so diversely, this type of data will be used for this research.

2) WSR-88D Algorithm Testing and Display System (WATADS)

The following information is taken from the WATADS Version 9.0 Reference Guide (Davis, 1996). WATADS is a software package developed by the NSSL to process, analyze, and display WSR-88D data. In addition, WATADS provides a means for NSSL to create new NSSL enhanced algorithms and to experiment with current WSR-88D algorithms. The WATADS software package is designed to run on SUN UNIX

workstations, and uses Level II data from the WSR-88D. This provides meteorologists the ability to test a large number diverse concepts using the WSR-88D. Some of these concepts include researching adaptable parameters, studying algorithm performance, building case studies, and producing training scenarios. WATADS contains the same capabilities to loop, zoom, and filter images as in the WSR-88D system. This makes WATADS an easy system to learn for any experienced WSR-88D operator.

Radar Analysis and Display System (RADS) is the part of the WATADS software package used for visualization of meteorological algorithm output, including special product files, derived images, and trend information. This system allows the meteorologist to analyze radar data and meteorological algorithm output in great detail. RADS displays products such as base reflectivity, composite reflectivity, spectrum width, vertically integrated liquid, base velocity, and precipitation accumulation. System information such as the WSR-88D identifier, date, time, elevation angle, and operational mode of the radar is also provided. WATADS has specific capabilities in periods of severe weather phenomena. Algorithms such as mesocyclone, tornado, and hail detection are available. More importantly, for this research, the Storm Cell Identification and Tracking (SCIT) Algorithm allows the user to identify specific storm cells, and the future tracks of these cells. Output from all these algorithms can be displayed, stored, or printed in tabular format for easy use.

c. WSR-88D Build 9 Algorithms

The following information about the WSR-88D algorithms is taken from the WATADS Version 9.0 Algorithm Reference Guide (Davis, 1997). Build 9 is the latest

version of the NSSL algorithm package, and is the first version to use multiple reflectivity thresholds, which allows identification of individual reflectivity cores. This new research development is of significance to the meteorological community, since the algorithms can now identify individual storm cells, rather than one storm system.

This information describes the procedure of how these algorithms identify thunderstorm centroids. Descriptions and references about storm centroids in this thesis refer ONLY to these thunderstorm cells identified by the WSR-88D and its algorithms.

1) WSR-88D Build 9 Storm Segments Algorithm

The Build 9 Storm Segments Algorithm identifies radial sequences or segments of reflectivity. These sequences consist of continuous volume samples with reflectivity values greater than or equal to a certain threshold, and a combined length greater than a specified threshold. Table 1 contains a list of adaptable parameters for this algorithm. For this research, the default parameters in WATADS were used. The following characteristics are computed and saved for each segment: maximum reflectivity, mass weighted length, and mass weighted length squared. In addition, the following characteristics are saved for each segment: azimuth, reflectivity threshold, beginning range, and ending range, elevation scan, and the number of segments. All of these characteristics are then used in the Storm Cell Centroids Algorithm.

One primary limitation exits with the Storm Segments Algorithm. The algorithm occasionally has problems with non-meteorological targets. The algorithm makes no attempt to prevent anomalous propagation or clutter. Clutter filtering is applied in the WSR-88D; however, it is not always correctly or adequately applied. As a result,

Parameter	Low	High	Default
Maximum Number of Segments per radial	10	50	15
Maximum Slant Range	230	460	460
Maximum Number of Segments per elevation	4000	6000	6000
Mass Coefficient Factor	1.2	1.5	1.37
Mass Multiplicative Factor	450	550	486
Mass Weighted Factor	50000	60000	53000
Dropout Count Threshold	0	5	2
Dropout Reflectivity Difference Threshold	0	10	5
Number of Reflectivity Levels	1	7	7
Storm Reflectivity Threshold	0	80	60,55,50,45,40,35,30
Storm Segment Threshold	1	5	1.9
Reflectivity Average Factor	1	5	3

Table 1 Adaptable Parameters for the WSR-88D Storm Segments Algorithm (Davis, 1996)

non-meteorological targets can possibly be identified as storms cells in the storm cell centroid algorithm.

2) WSR-88D Build 9 Storm Centroids Algorithm

The Build 9 storm centroids algorithm distinguishes storm cells by sorting cell segments into components. Once the segments are sorted into components, the algorithm then computes attributes of these components. After computation, the components are vertically correlated into cells, then the cell's attributes are computed. A component is defined as a two dimensional area of significant reflectivity, and a centroid is the mass weighted center of a three dimensional region of significant reflectivity. Unlike previous versions of the storm centroids algorithm, the Build 9 version identifies individual high reflectivity cores within convective storms, instead of defining the volume of storms.

The algorithm first combines radially overlapping and azimuthally adjacent radial segments, taken from the Build 9 Storm Cell Segments Algorithm, into two dimensional components. Only segments on the same elevation scan with the same reflectivity threshold are combined. A component that has a minimum specified number of segments and a real vertical extent becomes a component.

Secondly, the algorithm searches for overlapping components of different reflectivity thresholds on the same elevation scan. If a component is found with a higher reflectivity threshold and contains the same boundaries, the component with the higher reflectivity threshold is kept, and the other is omitted.

Next, the components are vertically correlated and assigned to the same cell. Center of mass of components at adjacent elevation scans is compared for proximity to the x and y

plane. For every component, the distance from the center of each component in the next higher elevation scan is compared until a component is discovered within a specified search radius. Since the algorithm sorts components at each elevation by decreasing mass, components with the greatest mass are compared first. If no components are matched, the search radius is increased, and the comparison process is repeated.

If two centroids are close enough together, the cells are merged. This distance between the centroids is one of the adaptable parameters in Table 2. In addition, their bases and tops must be within a determined vertical and angular separation, which is also an adaptable parameter in Table 2. When two cells are merged, one cell's components are added to the other, and the new centroid is then computed.

Table 2 contains a list of all adaptable parameters for this algorithm. For this research, the default parameters in WATADS were used. The following characteristics are computed and saved for each cell: centroid, x-position, y-position, range, azimuth, height, maximum reflectivity, height of maximum reflectivity, base, top, vertically integrated liquid (VIL), and number of components. The algorithm outputs the following characteristics for each component: maximum reflectivity factor, height, elevation, x-position, y-position, range, and azimuth. To reduce crowding, cells within a certain specified horizontal distance are deleted. If two cells are within the specified distance, as defined in the adaptable parameters in Table 2, and if their cell depths are greater than a specified threshold, the cell with the lower cell-based VIL is deleted. Lastly, the remaining cells are sorted by cell-based VIL. If the cells cannot be sorted by VIL, they will be sorted by maximum reflectivity.

Parameter	Low	High	Default
Maximum Number of Storm Cells	20	100	100
Segment Overlap Threshold	0	5	2
Azimuthal Separation Threshold	1.5	3.5	1.5
Minimum Number of Segments	1	4	2
Maximum Number of Components	20	120	120
Maximum Number of Potential Components	10	100	70
Minimum Component Area	10	30	10
Search Radius Threshold (1)	1	10	5
Search Radius Threshold (2)	1	12.5	7.5
Search Radius Threshold (3)	1	15	10
Maximum Storm CellsDetectable	20	130	130
Maximum VIL Threshold	1	120	120
Depth Delete Threshold	0	10	4
Horizontal Difference Threshold	3	30	5
Horizontal Distance Threshold	5	20	10
Elevation Difference Threshold	1	5	3
Height Difference Threshold	1	8	4

Table 2 Adaptable Parameters for the WSR-88D Storm Centroids Algorithm (Davis, 1996)

Some limitations exist in the Build 9 Storm Centroids Algorithm. At long ranges, only lower elevation scans will contain components. At 120 nm, the 0.5 elevation angle is above 10,000 feet, and components must be found on a minimum of two successive volume scans to identify a cell. Therefore, cells at long ranges may not have the vertical extent to be identified; thus, no cells will be identified. Next, if the Storm Cell Segments Algorithm contained segments with non-meteorological targets, cells may be falsely identified. Another limitation deals with closely related cells. When a number of cells are close together, the algorithm may combine components on an elevation scan into one component. Also, the algorithm may combine a group of cells into one, or falsely spilt a cell into more cells. These problems; however, are extremely rare.

3) Build 9 Storm Cell Tracking Algorithm

The Storm Cell Tracking Algorithm observes the movement of storm cells. This algorithm tracks the movement of individual cells, not lines or areas of storms. The adaptable parameters for this algorithm are located in Table 3. This is done by matching storms found in the current volume scan with storms found in the previous volume scan in time and space, using a correlation table. Storm cells are matched by cell-based VIL, starting with the most intense cell. The cell's centroid position in the current volume scan is compared to the cell's projected centroid position from the previous volume scan. A cell's projected centroid position is the cell's forecasted position for the current volume scan. If a cell's projected centroid position is located within an adaptable range of the current cell, it is correlated and considered the same cell, and is then assigned the same storm cell identification number (CID). This step is repeated for the next most intense cell

in the current volume scan. The process continues until all cells in the current volume scan are processed. Once a cell is correlated, it is not compared to any other cells in the previous volume scan. If no projected centroid positions are within the adaptable range of a cell's centroid position, the cell is not correlated and is assigned a new CID. If more than a specified amount of time has passed between volume scans, all storm cells in the current volume scan are considered new.

Parameter	Low	High	Default
Speed Correlation	10	99	30
Maximum Time between Scans	10	60	20
Default Direction	0	360	225
Default Speed	0	99.9	25

Table 3 Adaptable Parameters for the WSR-88D Storm Cell Tracking Algorithm (Davis, 1996)

The Storm Cell Tracking Algorithm works best with isolated storm cells with invariable movement. The algorithm's performance may be reduced with extremely erratic storm motion, rapid storm evolution, and decay. Cell splits or mergers, especially if the storms are very close together, will reduce algorithm performance. In addition, algorithm performance will be diminished in cells that move quickly in different directions. Although algorithm failures due to the above circumstances are uncommon, the frequency of occurrences is unknown.

4) Differences between WSR-88D Algorithms and WATADS algorithms

A few subtle differences exist between the WSR-88D Storm Cell Identification and Tracking Algorithm (SCIT) and the WATADS SCIT algorithm. Both algorithms use the same criteria to define storm cells; however, a few differences do exist. First, the reflectivity data in the WATADS SCIT algorithm is truncated to whole dBZ, unlike the WSR-88D SCIT algorithm, where the resolution of the reflectivity is one half a dBZ. As a

result, average maximum reflectivities computed by the WATADS SCIT may be slightly less than the WSR-88D SCIT. Next, the parameters used to rank storm cells differ between the two algorithms. The WSR-88D SCIT algorithm ranks storm cells by the magnitude of their cell-based VIL, and then by their maximum reflectivity. The WATADS SCIT ranks storm cells by the magnitude of the Severe Hail Index (SHI), and then by maximum reflectivity, only if any of the top twenty storms have a SHI of zero.

d. Research Developments

Lightning research has consisted of correlating reflectivity and radar data with lightning strikes for the purpose of better forecasting lightning activity. Marshall and Radhakant (1978) correlated lightning activity to radar reflectivity at the six to seven km height in the atmosphere. Lhermitte and Krehbiel (1979) further researched this discovery, finding the start of electrical activity in thunderstorms began at the 8 km or -20°C level. They also discovered the peak flash rate occurred when radar reflectivity surpassed 50 dBZ at the -10°C level. Buechler and Goodman (1991) discovered that cloud to ground lightning started when reflectivity values of 30-40 dBZ extended above seven km. Harris-Hobbs (1992) correlated storm volumes with lightning activity. An Air Force Technical Report by Harris (1997) found that lightning activity is initiated at the conclusion of an early updraft, where the storm are in early developmental stages, and maximum reflectivity factors are at least 45 dBZ in the lower part of the storm.

None of these publications evaluated the horizontal distance between storm cells and lightning strikes. The main reason for this is the differences between Build 9 and previous versions. Before Build 9, evaluating horizontal distance between lightning strikes and

storm cells was very difficult since only one storm system could be identified. As discussed before, Build 9 identifies individual reflectivity cores, which makes the task of identifying individual storm cells easier. With the identification of individual cells, it is possible to analyze distances between individual lightning strikes with storm cells.

3. Methodology

a. Objective

The purpose of this research is to analyze horizontal distances between thunderstorm centroids and cloud to ground lightning strikes.

b. Scope

The first point considered in this thesis is where to perform the research. Florida contains the highest number of lightning strikes; however, military installations exist throughout the Gulf Coast. Research is needed in this region to avoid another incident similar to Hurlburt Field. Lightning is especially dangerous in the plains, especially during supercell thunderstorms in the summer. Additionally, numerous military installations are located in northern Texas and the western half of Oklahoma. Table 4 shows the eight WSR-88D sites and nearby military installations used for this research.

The next consideration is for what time period should the research take place. The WSR-88D is a fairly new technological advancement in the meteorological community. Most WSR-88D units have been fully operational less than 5 years. Additionally, Level II data has been archived for just the past few years. This greatly limits the amount of radar data to be analyzed. Lightning and NEXRAD data will be used for the April and July of 1996, representative months of Spring and Summer.

Once locations and times were selected, the next step was to order the lightning data from the Air Force Combat Climatology Center (AFCCC) in Asheville, NC. Lightning data was acquired from March to August, within a 60 nm radius of each radar site in

Location	ID	Region	Latitude	Longitude	Local Military Installations
Tallahassee, FL	KTLH	Gulf Coast	30'35 N	84'19 W	Tyndall AFB
Eglin AFB, FL	KEVX	Gulf Coast	30'33 N	85'55 W	Hurlburt Field
					NAS Whiting Field
Mobile, AL	KMOB	Gulf Coast	30'40 N	88'14 W	Keesler AFB
New Orleans, LA	KLIX	Gulf Coast	30'30 N	98'49 W	NAS New Orleans
Dyess AFB, TX	KDYX	S. Plains	32'32 N	99'15 W	
Altus AFB, OK	KFDR	S. Plains	34'21 N	98'58 W	Sheppard AFB
Oklahoma City, OK	KTLX	S. Plains	35'19 N	97'16 W	Tinker AFB
Vance AFB, OK	KVNX	S. Plains	36'44 N	98'07 W	

Table 4 WSR-88D Sites chosen for this research, including local military installations of coverage

Table 4. The lightning data contained the following important information for this research: month, day, year, hour, minute, second, latitude, and longitude.

The next procedure was to order the NEXRAD Level II data. A synoptic analysis was first required to determine which days have large thunderstorms with plenty of lightning strikes. So, daily weather maps were examined for April and July. For each day, these maps contained only a 12Z 500 mb chart, surface map, 24 hour precipitation, and high and low temperatures With just this data, it was difficult to determine thunderstorms at the specified locations.

The best procedure to find thunderstorm days was to actually sum up the number of lightning strikes per hour, then match times with an abundance of lightning strikes to the available NEXRAD Level II data. A Fortran program was constructed to sum the number of lightning strikes per hour. Once the program was complete, the number of strikes per hour was compared to the NEXRAD Level II index on the AFCCC home page. In most cases, there was no difficulty matching large clusters of lightning strikes to Level II data. Some stations did lack archived Level II data, especially Eglin in the month of April, where no significant matches were found for Level II and lightning data. Appendix A contains the dates and times of the Level II data used in this research.

This research did not take into account the synoptic setting, type, or the differences between Gulf Coast and Southern Plains thunderstorms, for example, frontal, airmass, onshore. The category of thunderstorms, such as single-cell, multicell, or supercell, was also not considered in this thesis. Selection was based only on the availability of appropriate Level II data that matched a significant amount of lightning data.

Additionally, thunderstorms in this research are defined and identified by the WSR-88D and its WATADS SCIT Algorithms only.

Once the Level II tapes arrived, the next step was to process each tape on a Sparc 20 workstation. Next, the Storm Series Algorithm (WSR-88D SCIT algorithm) and the NSSL Series Algorithm (NSSL SCIT) were processed. The NSSL Storm Series contains two important output files for this research: fort.13 and fort.14. The fort.13 file contains the azimuth and range of the centroid from the RDA, the mass, volume, and area of the cell. The fort.14 file consists of the speed and direction of the storm cell. The output file used from the WSR-88D Storm Series Algorithm is the 3D.dat file. This file contains the height of the base of the storm cell, the height of the top of the storm, maximum reflectivity, and the height of the maximum reflectivity. Examples of these three files are located in Appendix B.

c. FORTRAN Programming

The next task was to combine the fort.13, fort.14, and 3D.dat files into one large data file. The Fortran program for this procedure is located in appendix C. The first step was to read in all the data. Files from fort.13 were first read into the program. The following is a list of pertinent information taken from the fort.13 file: hour, minute, second, number of cells, the storm cell identification number (CID), azimuth, range, direction, and speed. Next, the following information was read in from the fort.14 file: day, year, hour, minute, second, mass, volume, and area. The following information from the 3D.dat file was then read in: hour, minute, number of storms. The time from the 3D.dat file was checked with the time from the fort.13 file. If both the hour and minute of both files matched, then the

data from the three files are from the same volume scan. Once the time was verified, the azimuth, range, height of the top of the storm, height of the bottom of the storm, maximum reflectivity, and the height of the maximum reflectivity was read in from the 3D.dat file.

Next, the data between the fort.13, fort.14, and 3D.dat files must be correlated, since the storm cells are ranked and numbered differently between the these files. If the azimuth in both files is within one half a degree, and the range in the two files is within 1 nm, the storm cells are matched.

Now that all the pertinent information has been merged, the time of the volume scan is rounded off to the nearest minute. After the time conversion, azimuth and range of the storm cell is then converted to latitude and longitude. This task was accomplished using spherical coordinates and the spherical right triangle. The complete derivation of this transformation is located with the Fortran program in Appendix C. With spherical coordinates, this conversion is accurate to within ten meters.

Once latitude and longitude conversions are made, all the information is written to an output file. This file contains the following information: CID, year, month, day, hour minute, latitude, longitude, azimuth, range, direction, speed, mass, volume area, storm cell base, storm cell top, maximum reflectivity, and height of the maximum reflectivity. When the file is written, the array is zeroed out, and the process of combining the files is repeated for the next volume scan.

Now, to avoid limitations of unidentified cells at long ranges, the lightning data must be filtered to exclude all lightning strikes greater than a 60nm radius of each radar.

Another Fortran program was written to perform this task. This program is found in Appendix D. Using spherical coordinates, the formula for the distance between two latitudes and longitudes is as follows:

DIST = R * (ACOS (SIN(LAT1) * SIN(LAT2) + COS(LAT1) * COS(LAT2) * COS(LON1-LON2))

In the above equation, R is the radius of the earth, LAT1 and LAT2 are the latitude and longitude of the first location, LAT2 and LONG2 are the latitude and longitude of the second location. All the lightning strikes within a 60nm radius for each RDA was written into a separate file.

Now that the lightning data and all the information for each volume scan is ready, another program was constructed to merge the two data sets, and finally compute the distance between storm cells and lightning strikes. The Fortran code for this procedure is located in Appendix E. The first part of the program consists of reading one volume scan's worth of data. The most recent volume scan read in is called the "current" volume scan. Next, the data for the first lightning strike is read in, rounded to the nearest minute, and the lightning latitude and longitude are converted to an azimuth and range from the RDA. Next, times of the two data sets are then compared. The process is repeated until an exact match of time between the two data sets is found.

When the first match is found, the distance between the lightning strike and the centroid is processed. Distances for all the cells within the volume scan are calculated, and the shortest distance is kept, with the assumption that the lightning strike did come from the storm cell with the closest distance between each individual cell and the

cloud-to-ground lightning strike. Then, the distance from the edge of the storm to the lightning strike is computed. This distance is processed using the area of the storm cell. Assuming a circular-shaped storm cell, the radius of the storm is computed. This distance from the lightning strike to the storm is then subtracted from the radius of the storm to get the distance from the edge of the storm to the lightning strike. A negative distance indicates the lightning strike is within the radius of the storm cell.

After these distances are computed, the azimuth angle from the storm cell's direction of motion to the lightning strike is then calculated. First, the azimuth and range from the storm cell to the lightning strike is computed. From this azimuth, the azimuth from the motion of the storm cell to the lightning strike is then calculated. After this computation, all the information about the lightning strike and the storm cell is written to a new file. A complete derivation of this coordinate transformation is located with the Fortran program in Appendix E.

Once one complete volume scan has been processed, the volume scan is saved into a temporary "old" volume scan file. The next set of lightning data is read in. If the time matches the old volume scan, distances are processed. If the times do not match, a new volume scan is read in. If the lightning strike is between volume scans, the storm cells must be interpolated to determine the location of the cell between volume scans at the same time of the lightning strike. A storm cell location is determined in one of two ways. If the cell exists in both the current and old volume scans, the location of the storm cell is estimated by interpolation. If the cell exists ONLY in the old volume scan, and the speed and direction of the cell is known, a new latitude and longitude is calculated. In either

case, the new latitude and longitude will match the time of the lightning strike. This process is repeated for all cells in the volume scan.

After new latitudes and longitudes are calculated, a new azimuth and range from the RDA to the storm cell is computed. Distances are then computed in the same way as non-interpolated latitudes and longitudes.

These two programs were run for April and July, for each of the eight radar sites. The output file for the second program consists of the following information: storm cell ID, month, day, hour, minute, distance between the lightning strike and storm cell, distance between the lightning strike and storm edge, latitude and longitude of the lightning strike and storm cell, azimuth and range of the lightning strike and storm cell, storm speed and direction, azimuth angle between storm direction and the lightning strike, mass, volume, area, height of the top and bottom, maximum dBZ, and height of the maximum dBZ. Next, the data was imported into a spreadsheet for statistical analysis. The heights of the 0°C, -10°C, and -20°C temperatures are added to the spreadsheet. These temperature heights were obtained from local upper air sites near each RDA.

4. Results

a. Overview

Results are organized into numerous categories. These categories consist of all lightning strikes, lightning strikes when the centroid's maximum reflectivity is between 30 and 40 dBZ, 40 and 50 dBZ, 50 and 60 dBZ, greater than 60 dBZ, lightning strikes from thunderstorm anvil (as defined below), lightning strikes ahead/behind the thunderstorm, lightning strikes outside storm area, lightning strikes when the height of maximum dBZ is above the 0°C line, -10°C line, and -20°C. These categories are organized by month, site, and region. All distances between storm cells and lightning strikes are in nautical miles. Figure 2 is a histogram of the number of lightning strikes per hour for the Level II data used in this thesis. A separate category will classify all lightning strikes when 100 or fewer strikes occurred in one hour. A description of errors follow these categories. Curve fitting and cumulative distributions of all horizontal distances by site conclude this chapter. Statistical analysis in this chapter was accomplished by spreadsheet and statistical software.

b. All Lightning Strikes

Figures 3 - 17 are histograms of all the lightning strike distances for each of the radar sites. Table 5 contains the mean and median for each location and region. The mean and median distances for all radar sites are longer in April than in July. Additionally, all the median distances are shorter than the mean distances, due to the large number of lightning

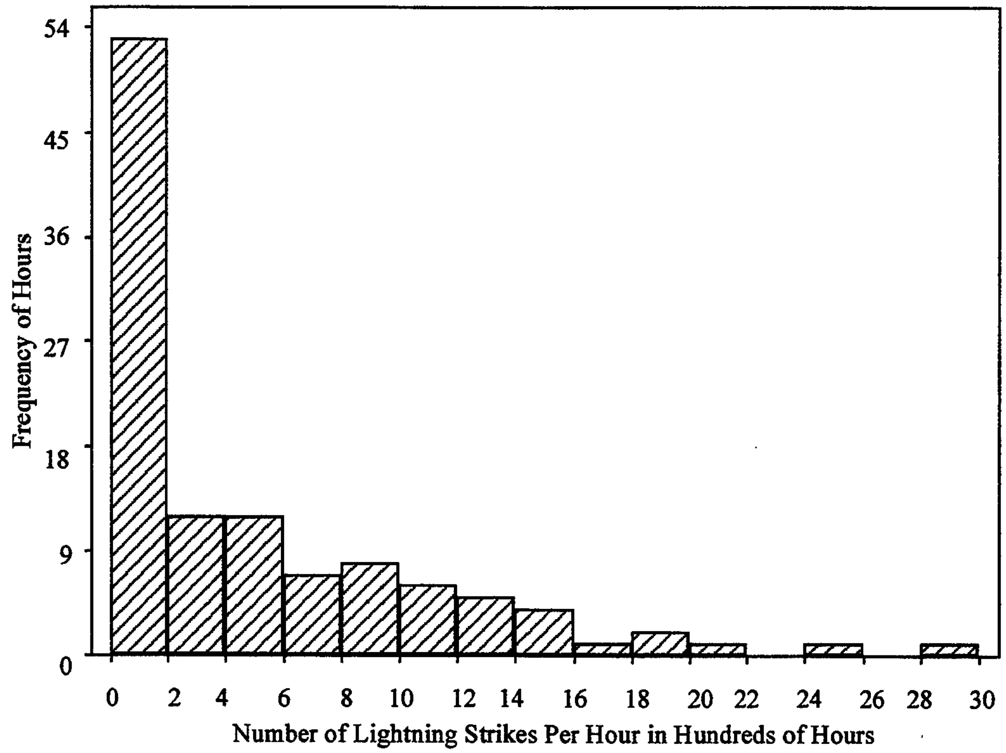

Figure 2 Histogram of Number of Lightning Strikes for Level II Data

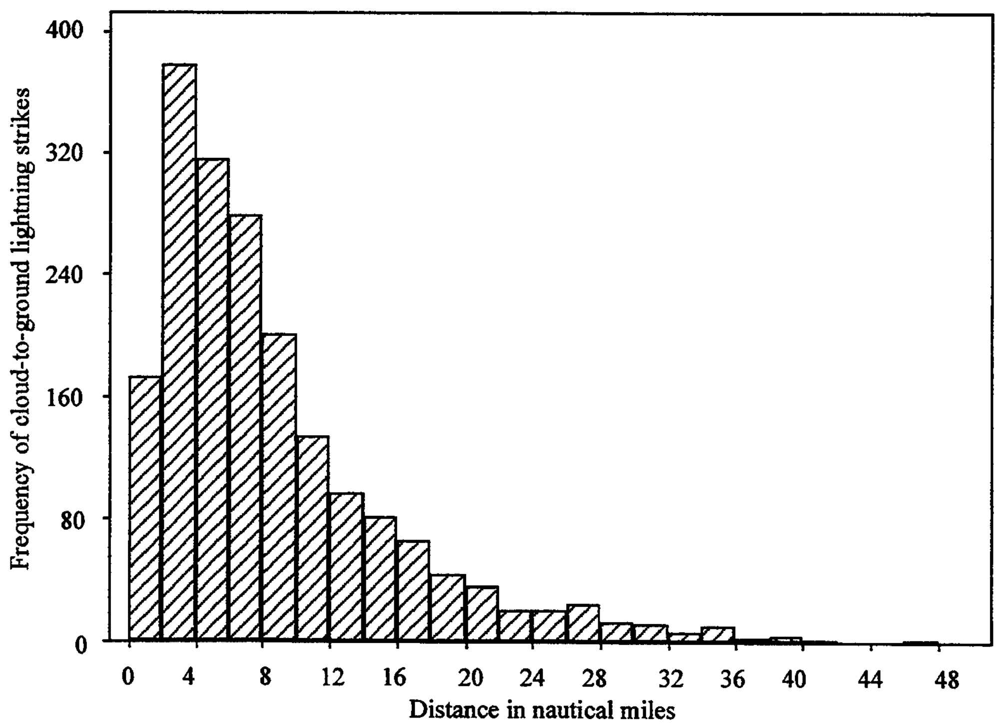

Figure 3 Histogram of all distances for DYX -- April

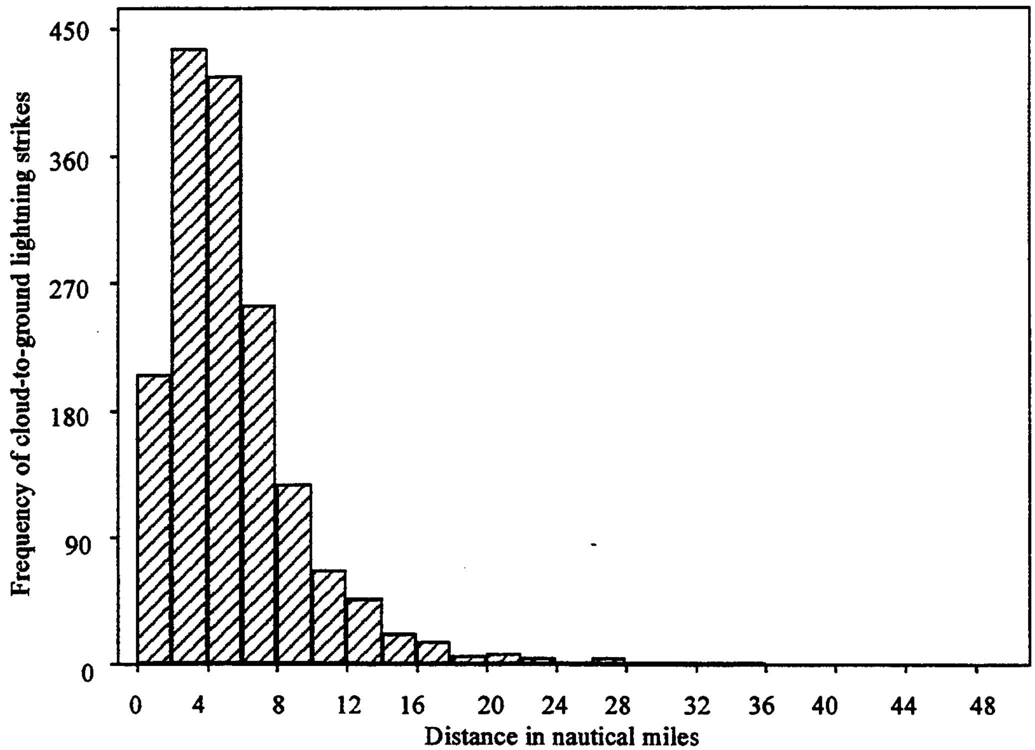

Figure 4 Histogram of all distances for FDR -- April

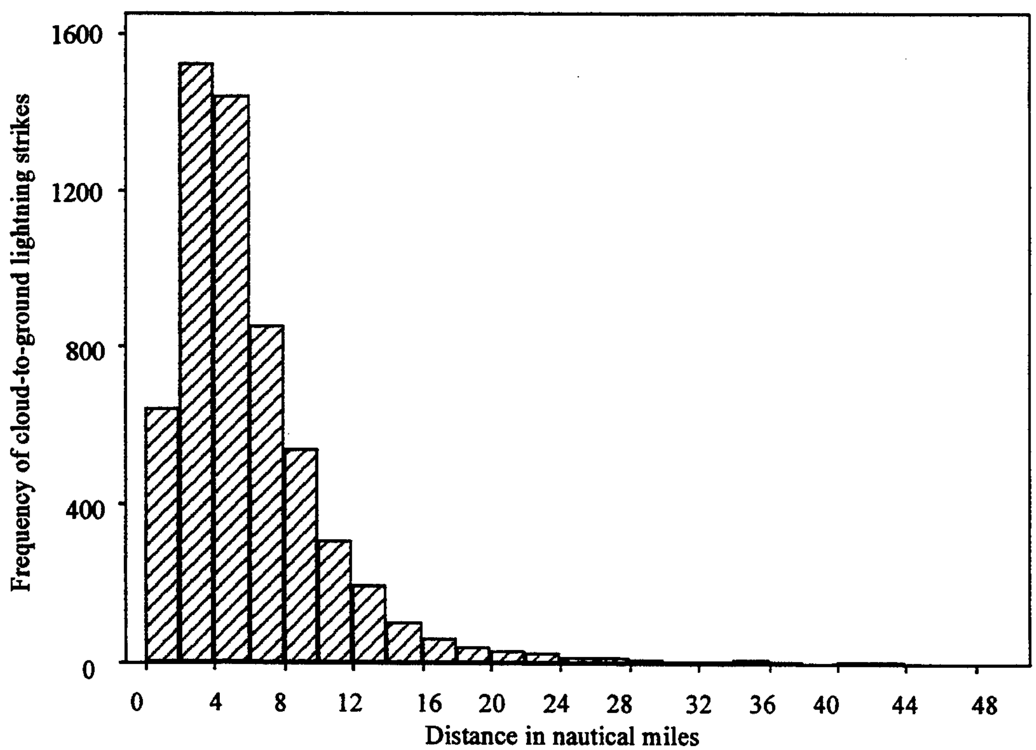

Figure 5 Histogram of all distances for LIX -- April

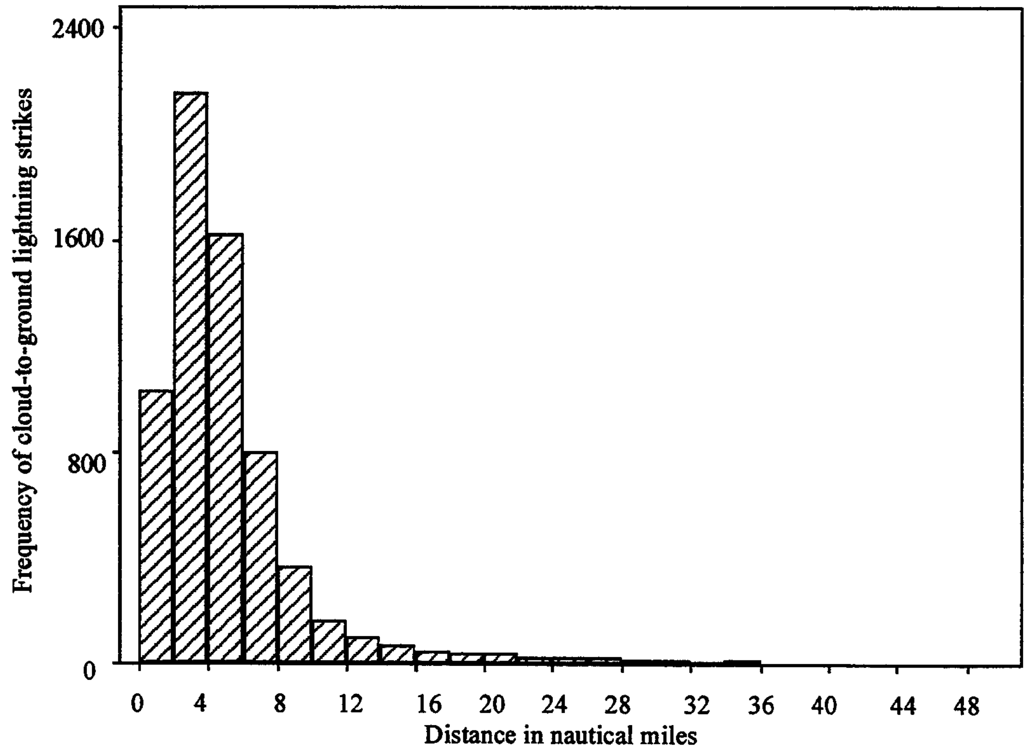

Figure 6 Histogram of all distances for MOB -- April

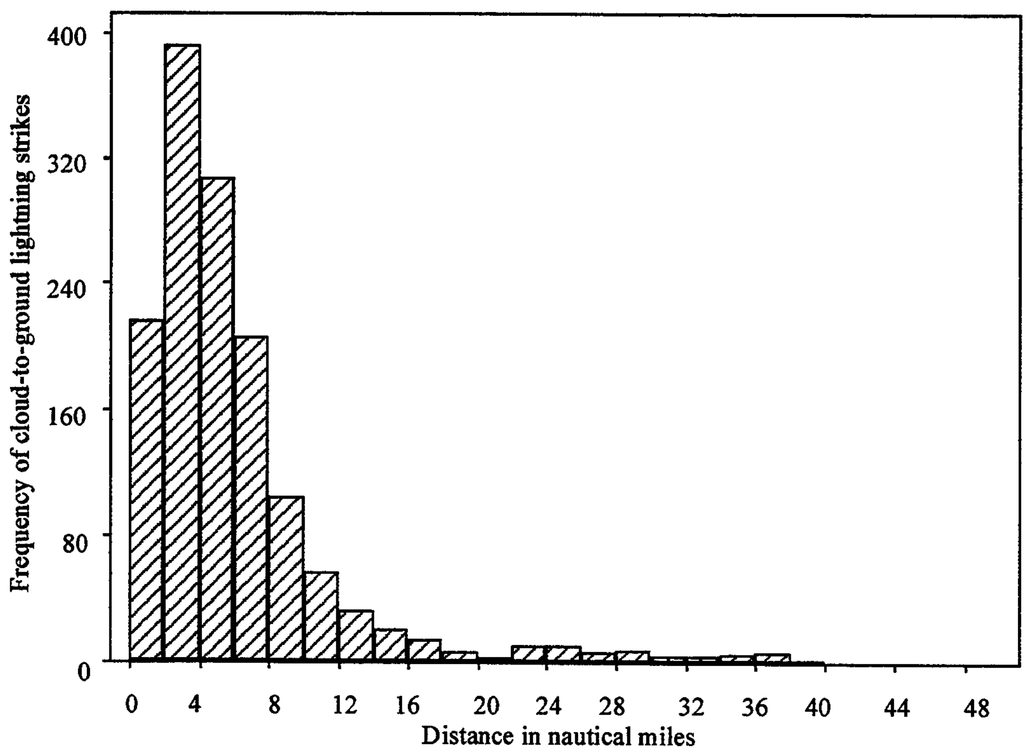

Figure 7 Histogram of all distances for TLH -- April

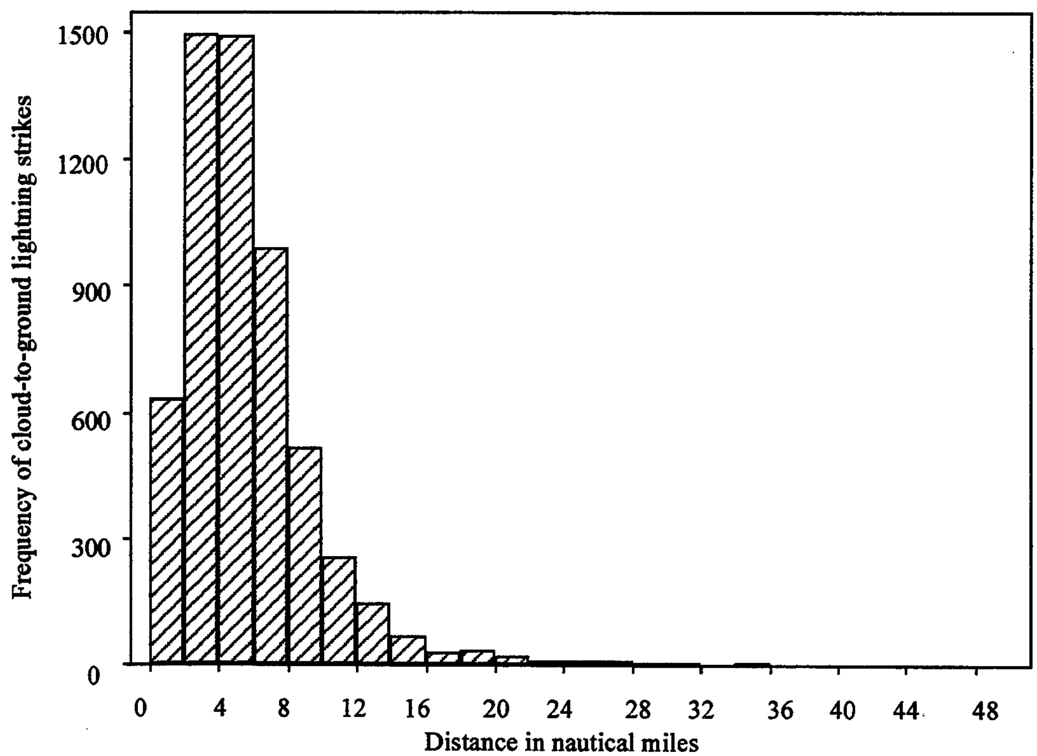

Figure 8 Histogram of all distances for TLX -- April

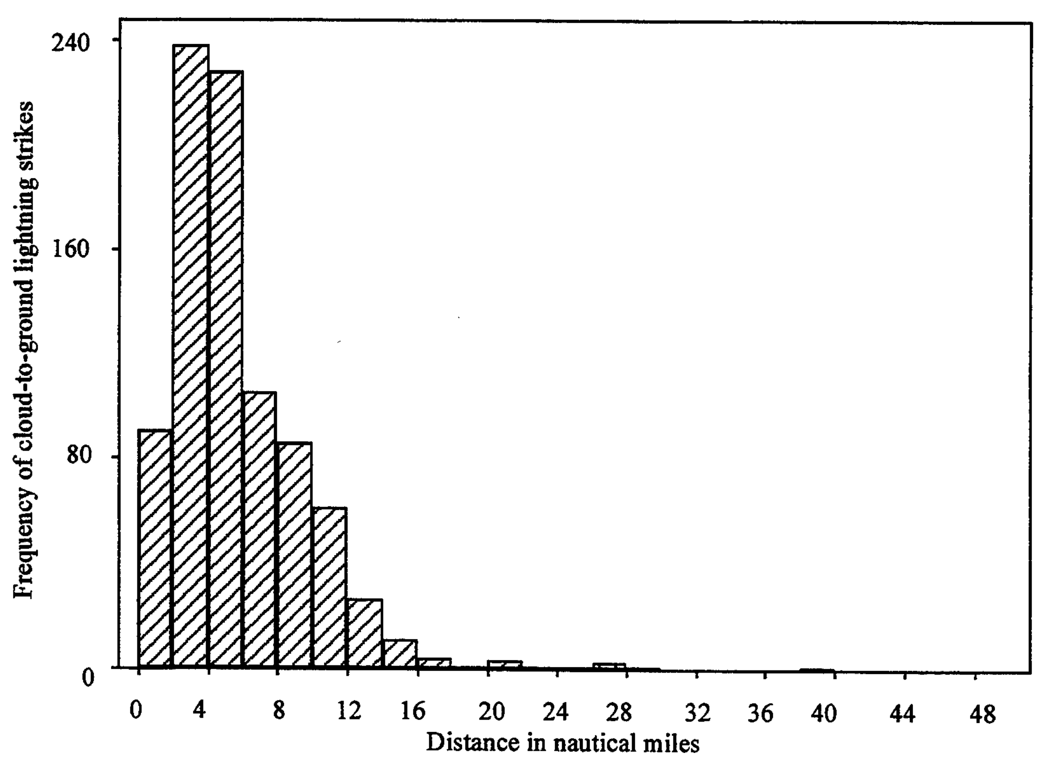

Figure 9 Histogram of all distances for VNX -- April

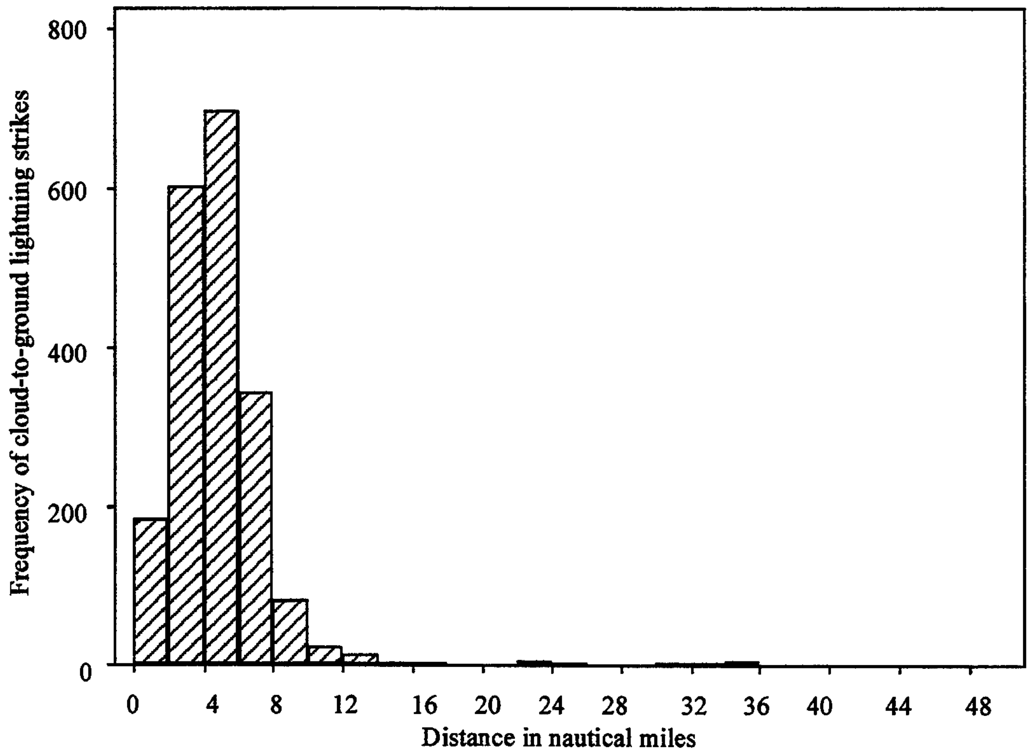

Figure 10 Histogram of all distances for DYX – July

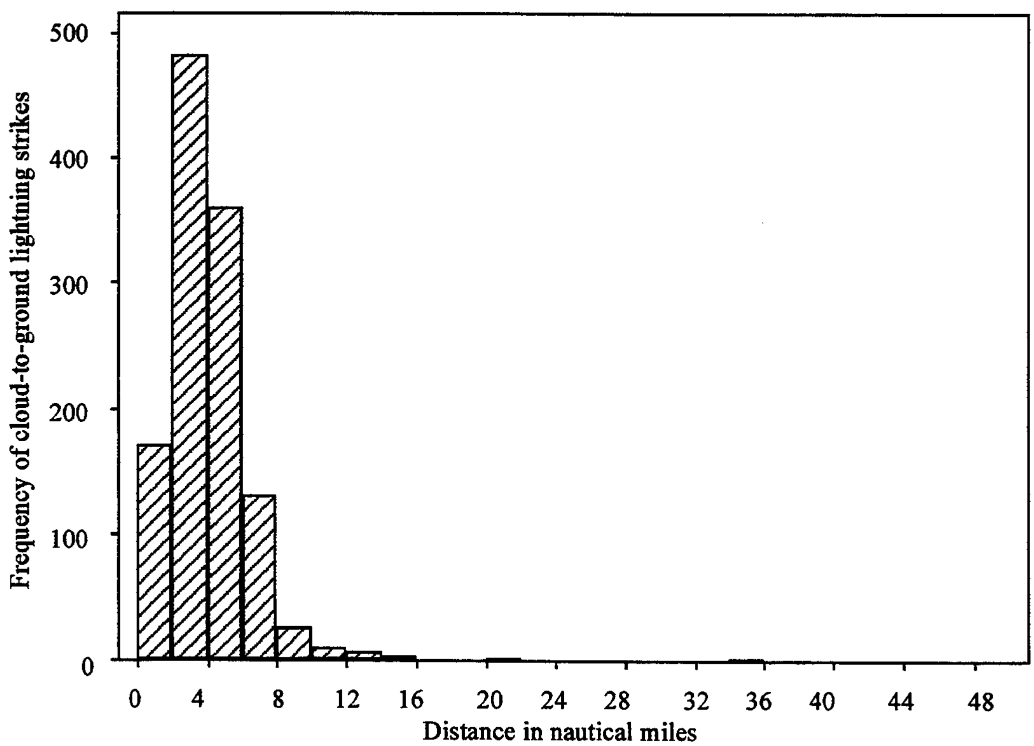

Figure 11 Histogram of all distances for EVX – July

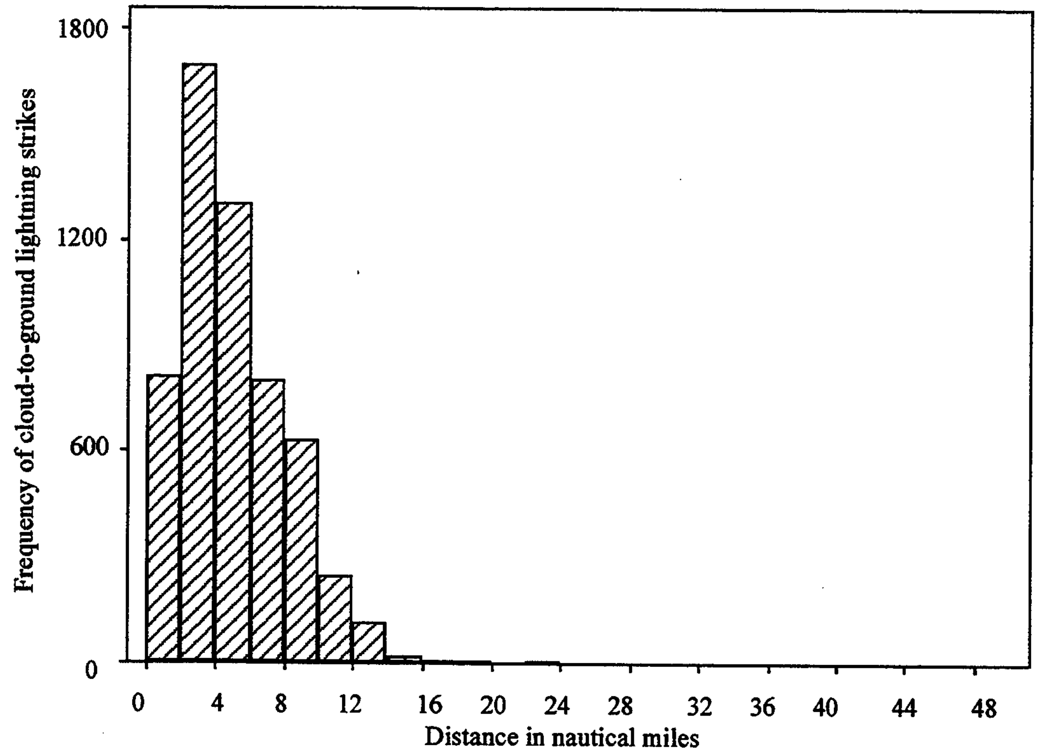

Figure 12 Histogram of all distances for FDR – July

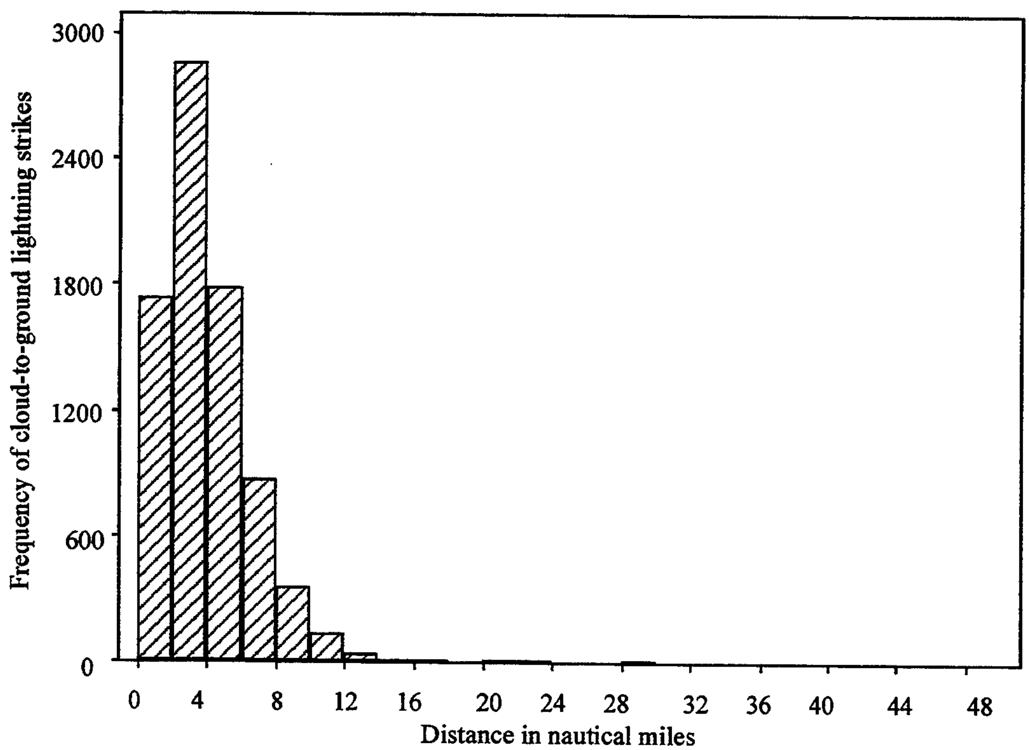

Figure 13 Histogram of all distances for LIX -- July

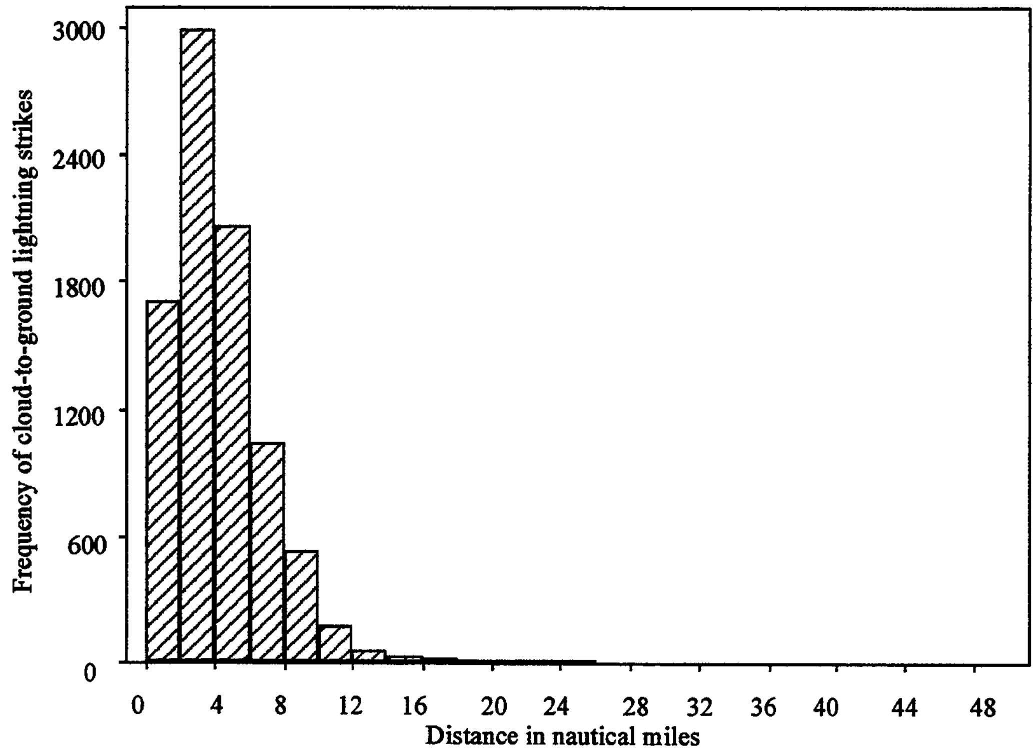

Figure 14 Histogram of all distances for MOB – July

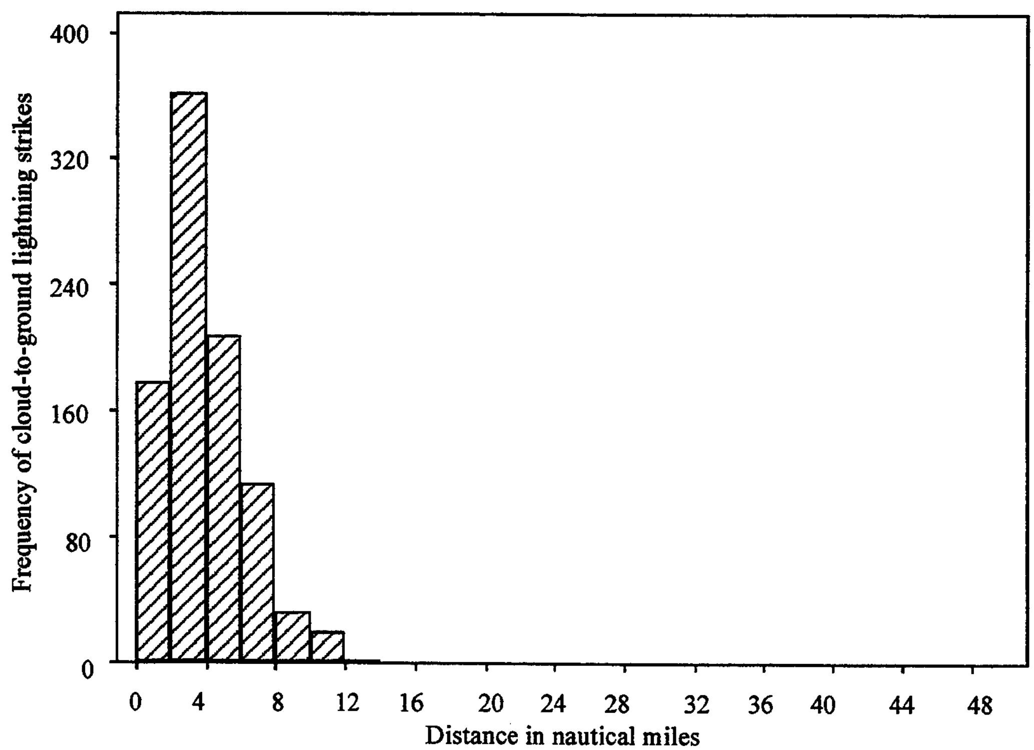

Figure 15 Histogram of all distances for TLH -- July

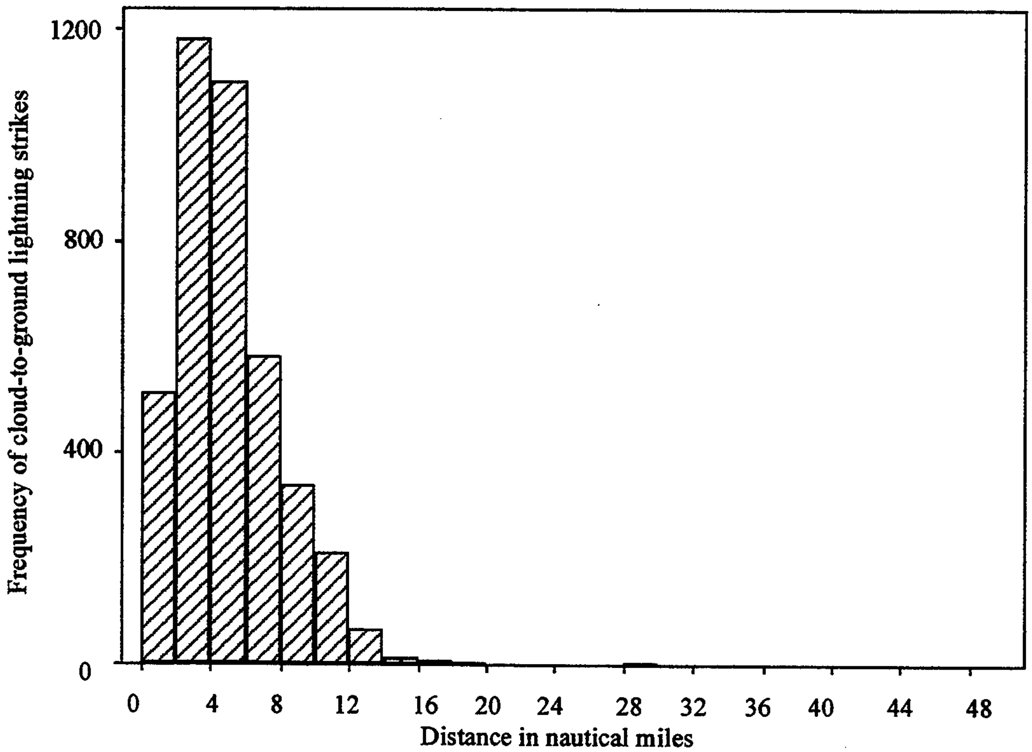

Figure 16 Histogram of all distances for TLX – July

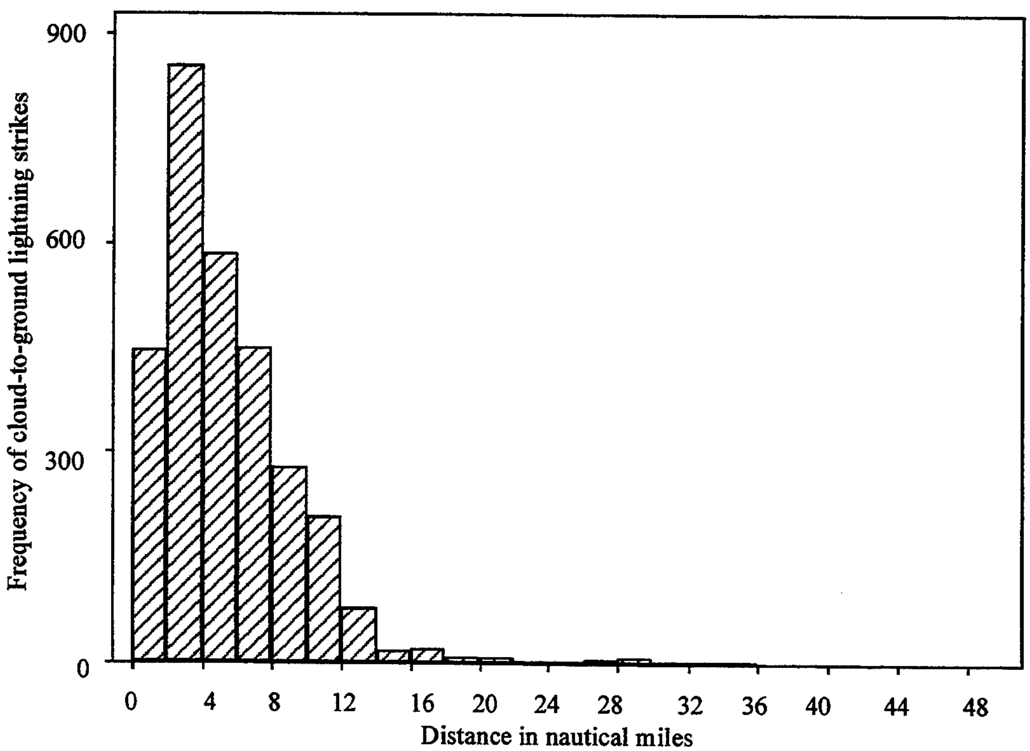

Figure 17 Histogram of all distances for VNX -- July

SITE	MEAN		MEDIAN	
	APRIL	JULY	APRIL	JULY
DYX	8.63	4.92	6.62	4.54
EVX	N/A	4.06	N/A	3.78
FDR	5.65	5.07	4.73	4.38
LIX	6.24	4.02	4.96	3.48
MOB	5.29	4.33	4.11	3.71
TLH	6.16	3.92	4.57	3.48
TLX	5.72	5.07	4.95	4.53
VNX	5.74	5.64	4.81	4.59
Gulf Coast	5.78	4.16	4.48	3.61
S. Plains	6.26	5.17	5.11	4.49

Table 5 Mean and Median Distances for all Strikes

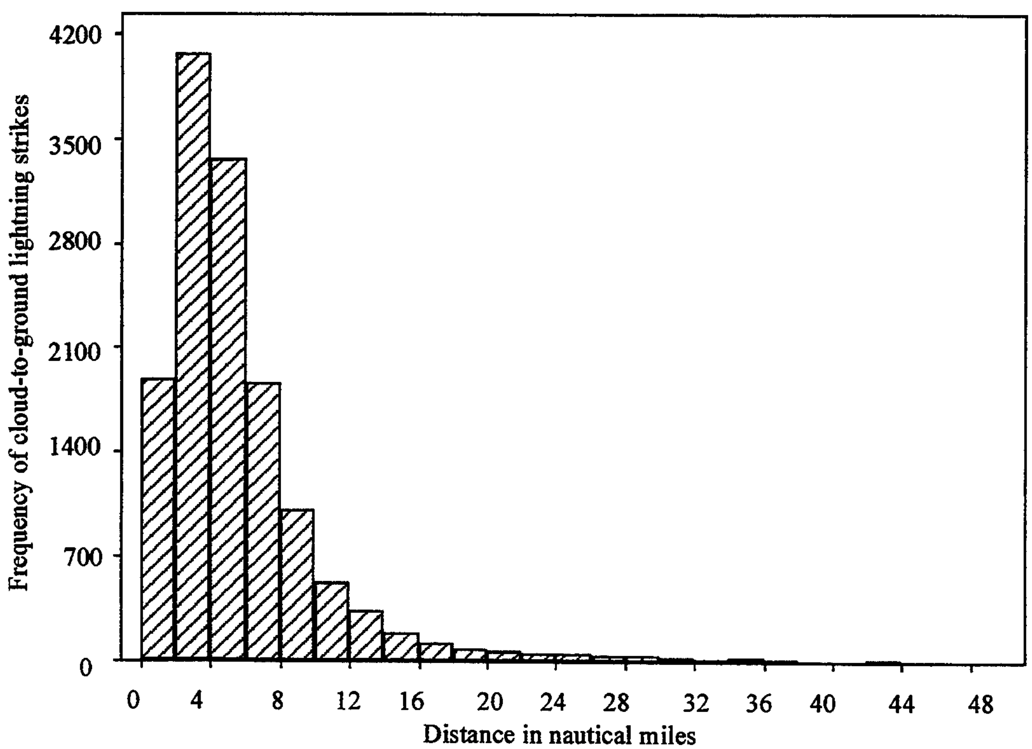

Figure 18 Histogram of all distances for Gulf Coast -- April

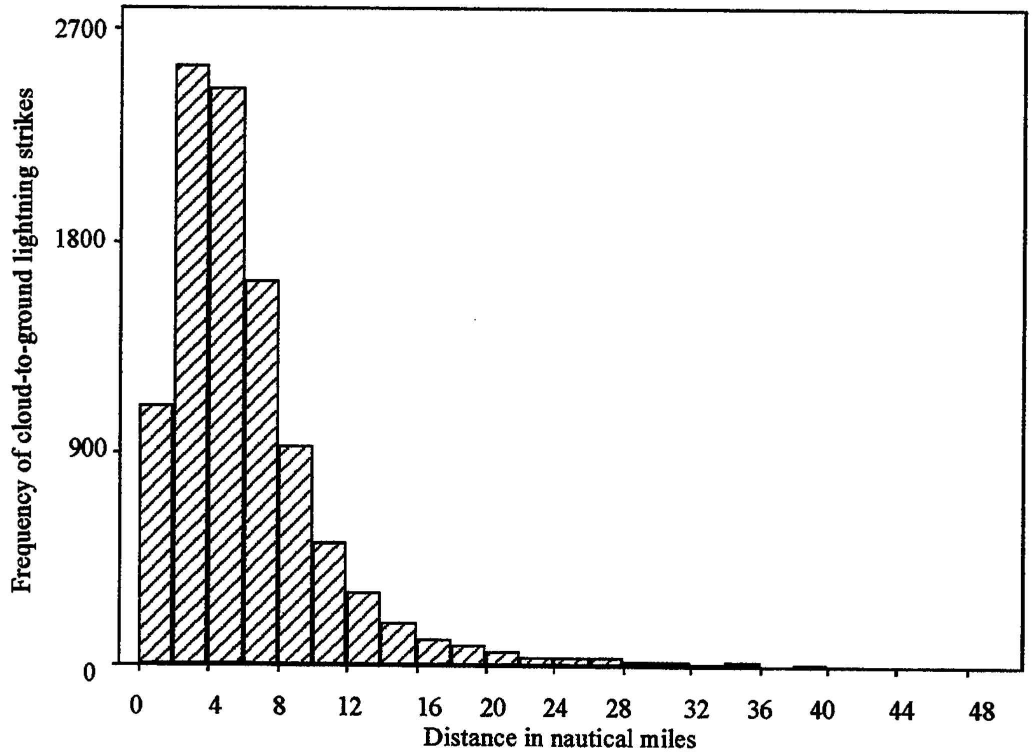

Figure 19 Histogram of all distances for Southern Plains -- April

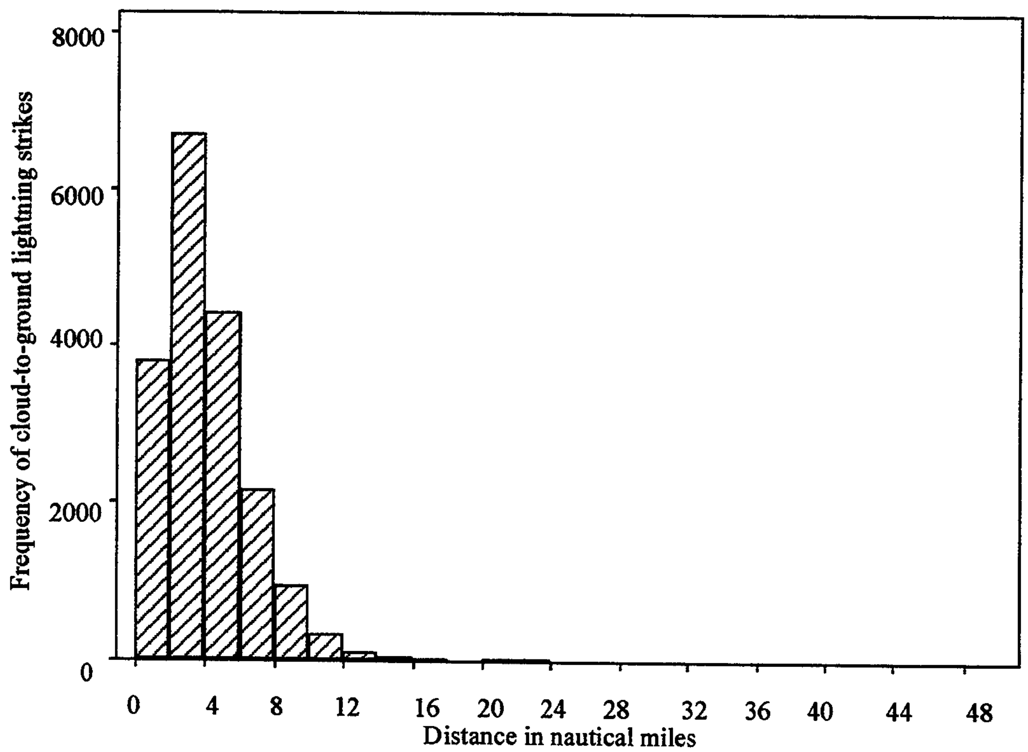

Figure 20 Histogram of all distances for Gulf Coast -- July

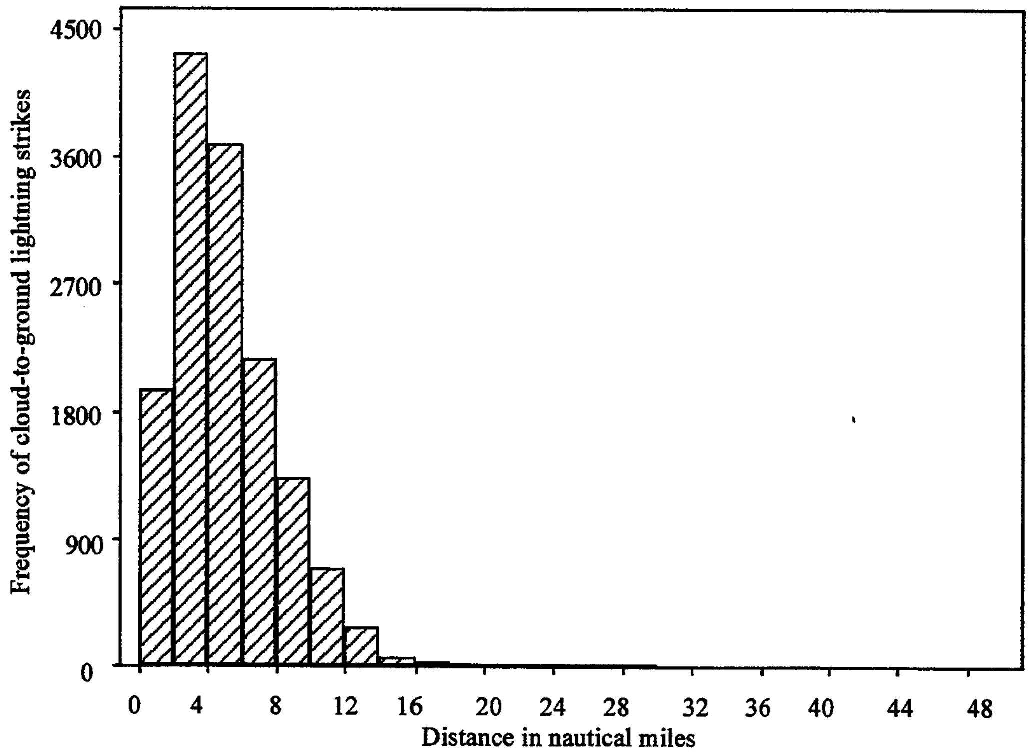

Figure 21 Histogram of all distances for Southern Plains -- July

strikes from 0 - 10nm, compared to the number of lightning strikes greater than 20nm. Histograms of both regions and months are displayed in Figures 18 - 21. Since EVX contained no Level II archived data in April, each space in the following tables for this category is labeled "N/A."

From these histograms, it is easy to see that ALL regions have similar distributions. Another important observation is the significant number of lightning strikes from two to six nautical miles. The greatest number of lightning strikes occur in this range at all radar sites. Additionally, a large drop-off of lightning strikes exists at distances greater than 16 nm. Some strikes exist past 16 nm; however, very few exist in this range compared to the total.

c. dBZ

The output was then categorized by dBZ. Since all of the Level II data did not contain maximum dBZ information, centroids without a given maximum dBZ are omitted for this statistical analysis. Tables 6 - 9 contain the mean and the percentage of lightning strikes within each dBZ threshold. No lightning strikes were observed from 30 to 40 dBZ for TLH in April, and EVX in July, as designated by “no strikes” in the following tables. Once again, a seasonal variation exits between the months of April and July, with a larger mean for most locations in April. Only the Southern Plains from 30 to 40 dBZ, VNX from 40 to 50 dBZ, contain a longer mean distance in July; however, TLH, TLX, VNX, and both regions contain a longer mean in July when the height of the maximum dBZ is greater than 60dBZ. An important observance is the decrease in the mean distance from 30 - 40dBZ to 40 - 50dBZ. In all but two cases the mean distance decreases as the maximum reflectivity increases. This holds true for all cases when comparing the means between 40 - 50 dBZ and 50 - 60 dBZ. The transition between 50 dBZ - 60 dBZ and greater than 60 dBZ is more complex, about half of the mean distances increase, the other half decreases. Categorized by region, the mean distance decreases in all cases except when comparing the 50 - 60 dBZ strikes with greater than 60 dBZ strikes in July. In both cases regions, the mean distance is higher in the greater than 60 dBZ category.

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	**JULY**	**APRIL**	**JULY**
DYX	11.33	7.66	8.27	0.96
EVX	N/A	no strikes	N/A	no strikes
FDR	7.17	5.66	3.44	4.61
LIX	8.11	5.99	1.48	0.23
MOB	6.78	6.47	0.87	0.57
TLH	no strikes	3.92	no strikes	1.01
TLX	6.15	5.71	1.64	1.12
VNX	9.11	7.45	2.25	1.79
Gulf Coast	7.76	5.99	1.05	0.41
S. Plains	8.44	6.62	3.32	2.61

Table 6 Mean Distances and Percentage of Strikes 30 to 40 dBZ

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	**JULY**	**APRIL**	**JULY**
DYX	10.3	5.17	36.68	18.52
EVX	N/A	4.37	N/A	12.51
FDR	6.24	5.31	14.24	38.34
LIX	5.81	4.18	19.29	9.27
MOB	6.21	4.58	10.35	13.79
TLH	8.57	4.25	8.37	3.63
TLX	6.63	5.25	15.75	15.91
VNX	6.06	6.71	13.77	18.92
Gulf Coast	6.11	4.42	13.91	11.26
S. Plains	7.31	5.49	19.41	25.69

Table 7 Mean Distances and Percentage of Strikes 40 to 50 dBZ

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	6.51	4.77	51.09	74.35
EVX	N/A	4.03	N/A	86.47
FDR	5.14	5.04	43.35	55.18
LIX	5.57	3.85	77.68	78.46
MOB	4.99	4.42	83.25	83.31
TLH	5.23	3.86	71.38	77.97
TLX	5.61	4.96	61.63	74.26
VNX	5.69	4.81	50.01	71.81
Gulf Coast	5.25	4.13	79.75	81.22
S. Plains	5.72	4.92	55.24	66.28

Table 8 Mean Distances and Percentage of Strikes 50 to 60 dBZ

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	7.52	4.18	3.96	6.13
EVX	N/A	3.79	N/A	0.94
FDR	5.83	3.56	38.97	1.88
LIX	5.78	4.69	1.55	12.04
MOB	4.21	4.04	5.52	2.32
TLH	3.32	4.41	20.14	17.39
TLX	5.05	5.23	20.98	8.69
VNX	5.17	7.99	33.98	7.47
Gulf Coast	4.07	4.55	5.29	7.11
S. Plains	5.39	5.62	22.03	5.43

Table 9 Mean Distances and Percentage of Strikes Greater than 60 dBZ

d. Lightning Strikes Outside Storm Area

Next, all the lightning strikes outside the area of the storm cell was categorized. The storm cell area is defined the area encompassing seven reflectivity cores of the storm cell. For this research, outside the storm area is outside the minimum reflectivity core, 30 dBZ. Precipitation can occur outside the storm area. Table 10 contains the percentage of lightning strikes outside storm area, along with the mean distance from the edge of the storm cell to the lightning strike. Once again, the mean distances for almost all the radar sites are greater in April than July; however, the mean distance for VNX is almost equal between the two months. In all cases, the percentage of lightning strikes outside the storm cell decreases between April and July.

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	6.67	2.47	67.71	59.97
EVX	N/A	1.99	N/A	54.91
FDR	3.68	3.19	62.24	59.81
LIX	4.53	2.57	56.94	50.16
MOB	4.26	2.78	52.08	50.56
TLH	5.21	2.25	55.64	53.97
TLX	3.74	3.16	64.01	58.71
VNX	3.81	3.81	55.96	52.36
Gulf Coast	4.48	2.61	54.51	50.83
S. Plains	4.29	3.19	63.67	57.98

Table 10 Mean Distances and Percentage of Strikes Outside Storm Cell Area

e. Anvil

The next category was by anvil. The anvil criteria is as follows: the lightning strike must be outside the storm area, and at a 45° angle to the right or left of storm forward motion. Table 11 shows the mean and percentage of all lightning strikes from the anvil. With the exception of VNX, mean distances are greater in April than in July, once again suggesting a seasonal variation.

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	9.72	6.61	14.02	18.35
EVX	N/A	5.44	N/A	4.31
FDR	7.992	6.59	18.83	13.96
LIX	8.45	5.37	12.07	13.78
MOB	7.86	6.44	12.84	13.06
TLH	6.79	5.34	12.21	9.25
TLX	7.28	6.03	18.41	7.145
VNX	7.09	8.33	12.93	10.69
Gulf Coast	8.02	5.87	12.45	12.63
S. Plains	7.72	6.82	17.26	12.03

Table 11 Mean Distances and Percentage of Strikes in the Anvil

f. Lightning Strikes in the Rear Flank of Storm Motion

The output was then categorized by lightning strikes in the rear flank of storm motion. The criteria is a follows: all lightning strikes in a 90° to 270° azimuth angle of storm motion. The percentage of lightning strikes behind storm motion is located in Table 12. With the exception of DYX, LIX, and the Gulf Coast, the percentage of lightning strikes behind the storm increases from April to July.

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	9.18	4.69	52.06	43.39
EVX	N/A	4.09	N/A	59.68
FDR	4.71	4.94	44.93	48.38
LIX	6.05	4.33	56.21	48.88
MOB	5.24	4.12	51.86	58.28
TLH	6.21	4.03	53.48	69.92
TLX	5.89	5.36	47.91	68.32
VNX	5.92	5.62	54.97	58.77
Gulf Coast	5.69	4.19	53.87	41.44
S. Plains	6.37	5.21	48.82	55.24

Table 12 Mean Distances and Percentage of Strikes in the Rear Flank of Storm Motion

g. Height of Maximum Reflectivity

The next category was organizing the data by the height of the maximum reflectivity, and comparing this to the height of the 0°C line. This data was sorted first by converting the upper air isotherms to thousands of feet, and then comparing these isotherms to the height of the maximum reflectivity (in thousands of feet) from the 3D.dat file. Table 13 contains the percentage of lightning strikes with the height of the maximum reflectivity above the 0°C line, in addition to the mean distance. In all cases, the mean distance is greater in April than in July. With the exception of VNX, the percentage of decreases from April to July. Table 14 shows the mean distances and percentage of lightning strikes with the maximum reflectivity above the -10°C line. For all radar sites, the percentage decreases from April to July. Table 15 displays the mean and percentage of lightning strikes with a maximum reflectivity above the -20°C line. No lightning strikes from storm cells with a maximum reflectivity higher than -20°C exist in this data set for DYX, EVX, FDR, LIX, and TLH. One observation is the small percentage of lightning strikes above -20°C, which is due to the lack of storm cells with the height of the maximum reflectivity greater than the -20°C line.

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	8.49	4.99	36.75	31.45
EVX	N/A	4.49	N/A	25.09
FDR	6.02	4.54	40.53	11.47
LIX	5.95	4.04	46.05	32.35
MOB	4.81	4.6	41.23	24.12
TLH	4.79	3.78	33.59	26.53
TLX	5.82	4.73	34.52	26.27
VNX	7.01	6.65	4.19	22.87
Gulf Coast	5.33	4.28	42.51	27.79
S. Plains	6.45	5.18	33.19	20.44

Table 13 Mean Distances and Percentage of Strikes Above 0°C Line

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	9.01	4.29	21.84	2.11
EVX	N/A	3.62	N/A	4.62
FDR	6.21	3.45	23.08	1.12
LIX	6.46	5.21	6.92	1.41
MOB	5.03	4.98	2.99	1.59
TLH	5.05	2.82	1.92	0.13
TLX	5.49	3.472	16.32	2.01
VNX	4.26	8.29	20.51	3.25
Gulf Coast	5.95	4.77	4.54	1.67
S. Plains	6.31	5.25	18.99	1.92

Table 14 Mean Distances and Percentage of Strikes Above -10°C Line

SITE	MEAN		PERCENT OF TOTAL STRIKES	
	APRIL	JULY	APRIL	JULY
DYX	9.78	no strikes	13.49	no strikes
EVX	N/A	no strikes	N/A	no strikes
FDR	6.84	no strikes	8.99	no strikes
LIX	3.11	no strikes	0.13	no strikes
MOB	3.93	3.15786	0.76	0.143
TLH	no strikes	no strikes	no strikes	no strikes
TLX	5.58	3.2689	6.24	1.24
VNX	3.72	9.77043	8.68	0.08
Gulf Coast	3.82	3.15786	0.42	0.06
S. Plains	6.97	3.56443	8.38	0.35

Table 15 Mean Distances and Percentage of Strikes Above -20°C Line

h. Less than 100 Strikes Per Hour

For less violent thunderstorms with diminished lightning activity, as in the case of the Hurlburt incident, this last category classifies all lightning strikes with less than 100 strikes per hour. For this category, Level II data could not be matched with lightning data during the month of July at the following radar sites: FDR, TLX, VNX. This is due to the lack of Level II archived data. Table 16 displays the mean distances, along with the mean distances for all lightning strikes. In comparison to all lightning strikes, some significant differences exist. The regional groupings show similar means in the Gulf Coast in April and July. The means of the Southern Plains differ by almost two nautical miles in April, but the difference decreases to one-fifth a nautical mile in July. Overall, differences between the means is less than one nautical mile, with the exception of DYX and VNX in April. DYX shows a dramatic difference of nearly five nautical miles in April, decreasing to less than a tenth of a nautical mile in July.

SITE	Less Than 100 Strikes Per Hour		All Lightning Strikes	
	Mean Distance			
	APRIL	JULY	APRIL	JULY
DYX	13.55	4.97	8.63	4.92
EVX	N/A	4.21	N/A	4.06
FDR	5.14	N/A	5.65	5.07
LIX	6.09	3.98	6.24	4.02
MOB	5.91	3.38	5.29	4.33
TLH	5.32	4.05	6.16	3.92
TLX	5.53	N/A	5.72	5.07
VNX	7.86	N/A	5.74	5.64
Gulf Coast	5.89	3.98	5.78	4.16
S. Plains	8.06	4.97	6.26	5.17

Table 16 Mean Distances for All Lightning Strikes and Lightning Strikes with Less Than 100 per hour

i. Errors

Errors may occur with the identification of storm centroids, as discussed in Chapter 2. Default parameters were used in this research to identify a storm centroid. Interpolating storm cells between volume scans increased the number of lightning strikes for analysis; however, the assumption of a straight moving storm cell was made. With disappearing storms, the cell is interpolated until the next volume scan only. Errors are involved with appearing storms between volume scans. In precipitation mode, volume scans are five to six minutes apart. If a storm cell appears right after a volume scan, four to five minutes may pass until the next volume scan; thus, no data is available to match this appearing storm with a lightning strike. This inability of the WSR-88D to identify developing storms may lead to errors, and therefore, matching lightning strikes to the wrong storm cells, or not matching a lightning strike to a developing storm.

To better verify horizontal distances between cloud-to-ground lightning strikes anc storm cells, 22 lightning strikes with distances from the strike to the storm cell greater than 20 nm were analyzed using WATADS. The analysis was performed at DYX on April 22nd, between 0823Z and 0936Z. DYX in April contain the most lighting strikes greater than 20 nm, as shown in Figure 3. The program was run twice, once without considering disappearing storm cells, and once with the disappearing storm cell algorithm of the Fortran program. Each lightning strike was verified using RADS. For the time period, eight lightning strikes greater than 20 nm were verified without the disappearing storm algorithm. After running the Fortran program with the disappearing storm algorithm, another six lightning strikes were matched with storm cells less than a 20 nm distance

between the cell and the lightning strike. One storm cell greater than 20 nm was identified with interpolation. Seven storm cells could have been matched with appearing cells. This test proves errors can result in matching lightning strikes and storm cells where nearby storm cells are developing.

Additional errors may result when considering boundary conditions. As stated in Chapter 3, the lightning data were used from within a 60nm radius of each RDA; however, ALL storm centroids were considered in this analysis. Data can be skewed when the storm centroid is just beyond and just inside the 60nm lightning radius. When storm centroids are greater than 60nm from the RDA, only lightning strikes within the 60nm radius are used. Thus, only lightning strikes further away from the storm centroid and inside the 60nm radius are taken into account, leading to a potentially higher mean distance. Conversely, data is skewed using storm centroids just inside the 60nm boundary. Lightning strikes closer to the storm centroid and inside the 60nm boundary are only accounted for; however, strikes further away from the centroid and outside the 60nm radius are not used, leading to a potentially shorter mean distance.

Data can also be biased when considering the "cone of silence" of the radar. The cone of silence is within a 10nm radius of the radar where the radar cannot identify storm centroids directly overhead due to the limitation of the radar system. The maximum elevation angle of the radar beam is 19°. Therefore, the radar has problems identifying storm centroids within 10nm of the RDA. Lightning strikes can be misidentified with storm centroids that the radar identifies outside the cone of silence; therefore, these lightning strike distances can be biased when considering this problem.

j. Curve Fitting and Cumulative Distributions

The next step in data analysis is to fit the horizontal distances into a statistical distribution. This task was accomplished using ExpertFit© (version 1.02) statistical software. This software ranks the best distributions using a relative score with 100.0 being the upper boundary. All the distances for each month and location were ranked by ExpertFit©. Appendix F displays the top ten distributions for each site in April and July. From this Appendix, the best distribution for this data is the Gamma distribution. Eight of the 15 data sets have the Gamma distribution as the best fit, and another 3 data sets have the Gamma distribution ranked second. The Gamma distribution is never ranked lower than seventh. So, the Gamma distribution will be the distribution of choice for this data.

Once the Gamma distribution was selected, the next task was to graph the cumulative probability distribution function (CDF). The CDF is the probability that a random variable will take on a *less than or equal to* a specified value. The CDF is a function of the lightning strike distance data, and the Gamma distribution is only a model of the true CDF. The CDF graph is obtained through the following equation:

$$F(x; \alpha, \beta) = \int_0^x (1 / \beta^\alpha \, \Gamma(\alpha)) \, (x^{\alpha-1}) \, (e^{-x/\beta})$$

Alpha is the shape and beta is the scale. "X" is the range of horizontal distances from the lightning strike to the storm cell, with the minimum distance zero, and the maximum distance 50. Values of alpha and beta are calculated in ExpertFit. Table 17 contains the values of alpha and beta for each of the radar sites. Once alpha and beta are known,

the graph of the CDF can be computed. data, and the CDF graphs for each of the sites is found in Figures 22 - 36. Distances in nautical miles are along the x-axis, and the probability (in percent) is along the y-axis.

SITE	APRIL		JULY	
	ALPHA	**BETA**	**ALPHA**	**BETA**
DYX	1.72	5.03	3.27	1.51
EVX	N/A	N/A	3.44	1.18
FDR	2.21	2.45	2.52	2.01
LIX	2.06	3.02	2.38	1.691
MOB	1.89	2.79	2.29	1.85
TLH	1.64	3.7	2.89	1.534
TLX	2.44	2.34	2.71	1.88
VNX	2.42	2.37	2.76	2.04

Table 17 Computed Values of Alpha and Beta using ExpertFit

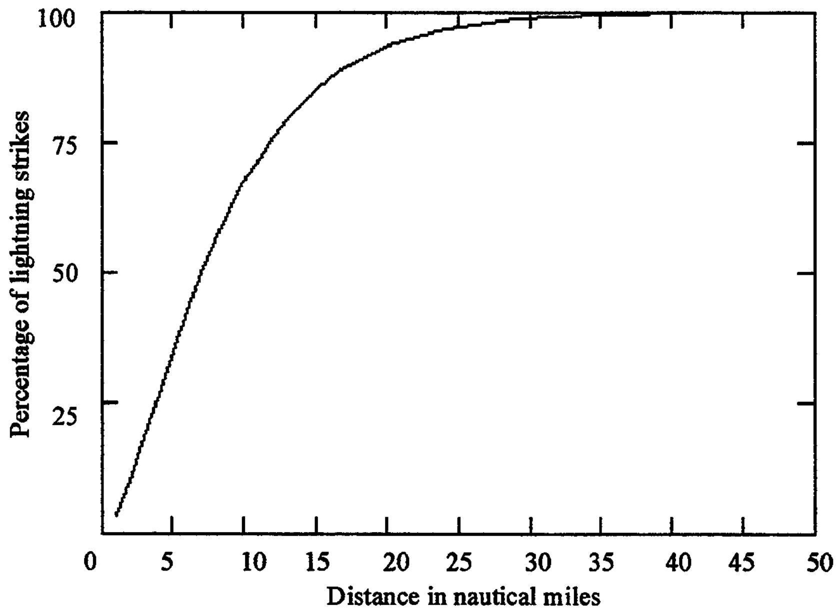

Figure 22 CDF of DYX -- April

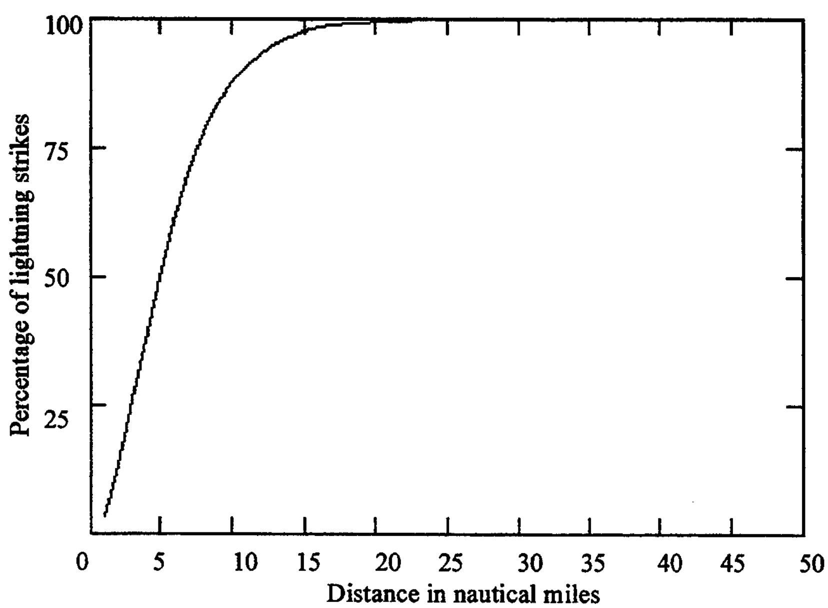

Figure 23 CDF of FDR -- April

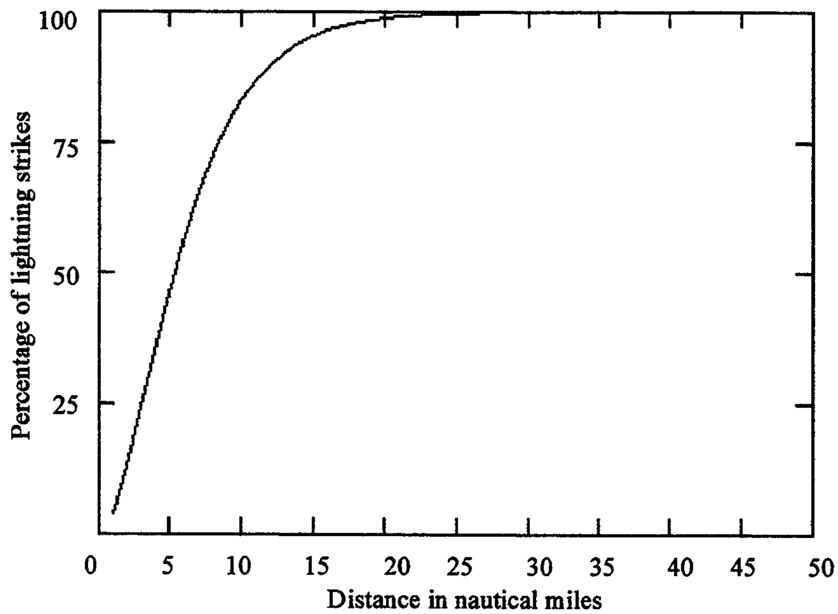

Figure 24 CDF of LIX -- April

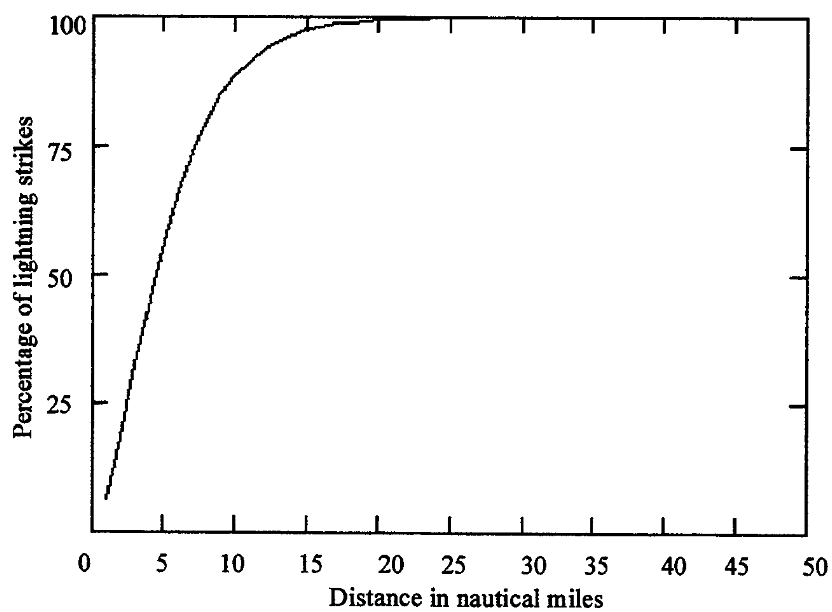

Figure 25 CDF of MOB -- April

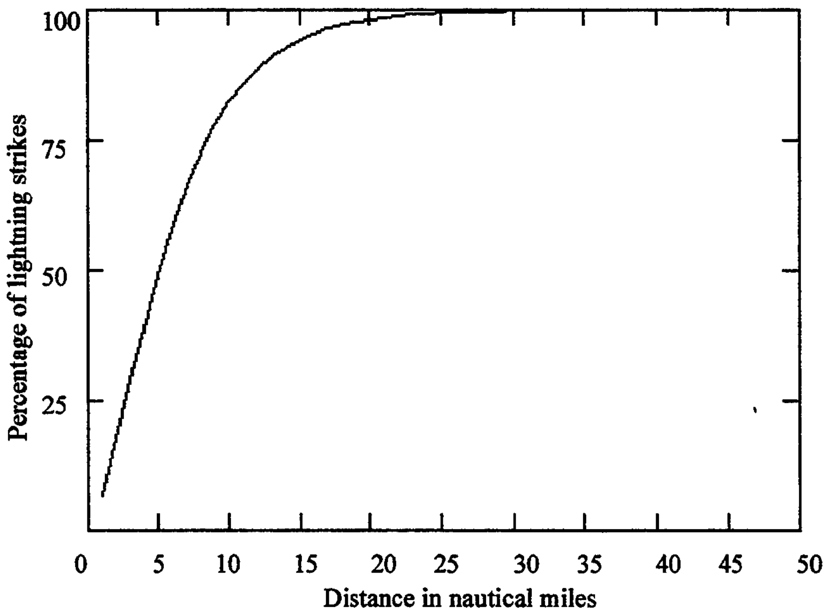

Figure 26 CDF of TLH -- April

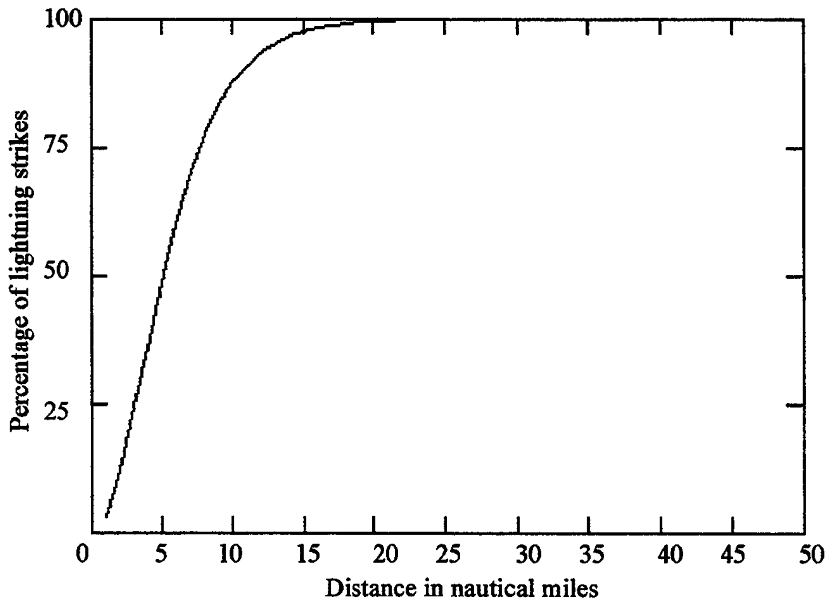

Figure 27 CDF of TLX -- April

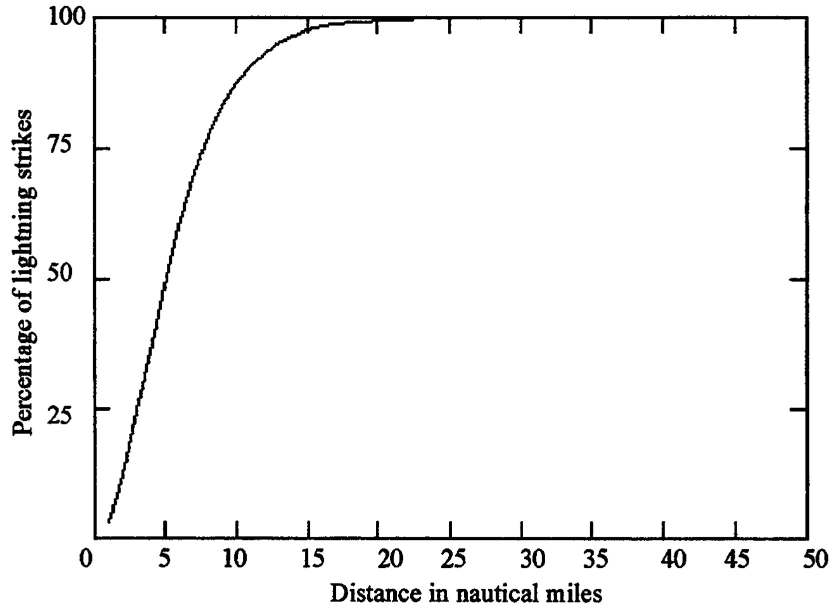

Figure 28 CDF of VNX -- April

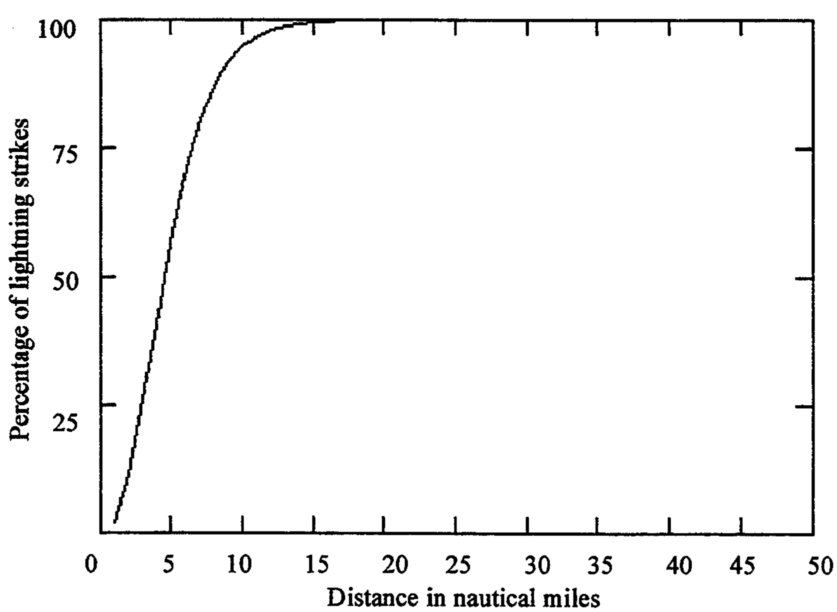

Figure 29 CDF of DYX -- July

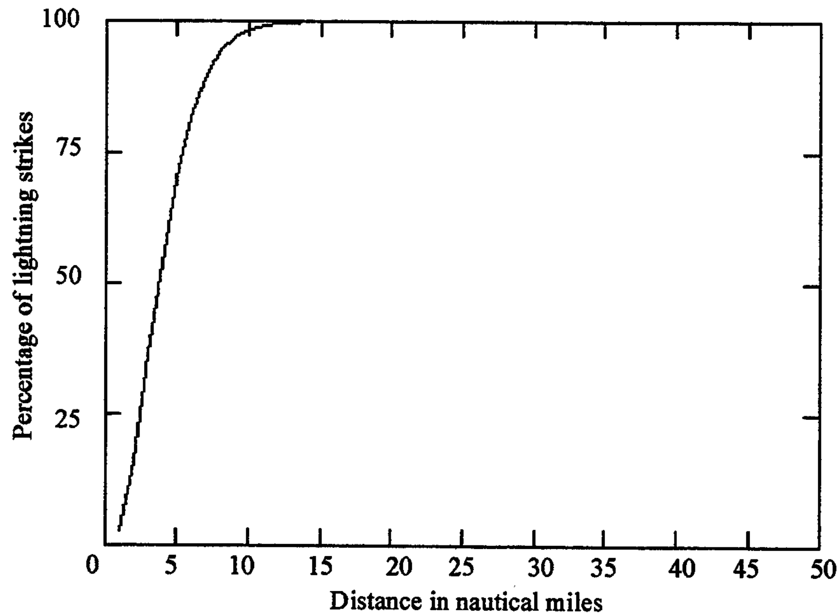

Figure 30 CDF of EVX -- July

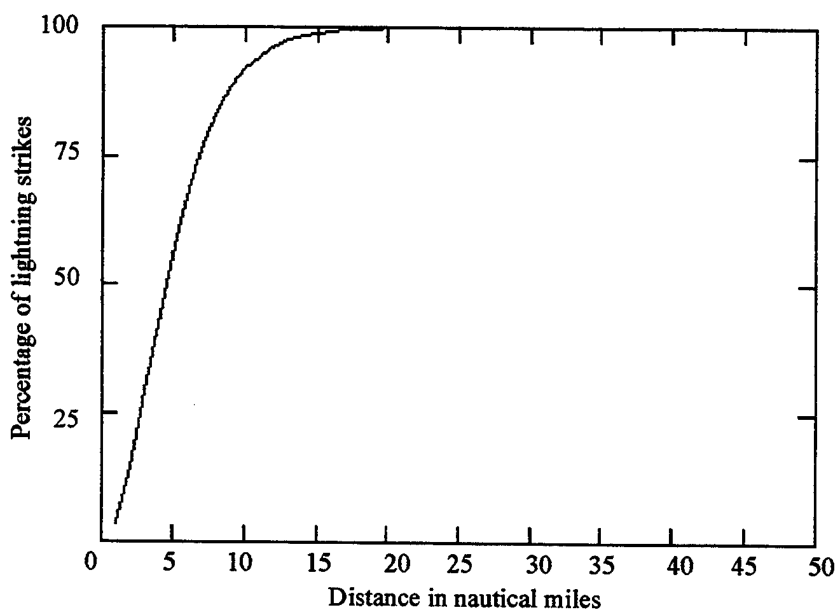

Figure 31 CDF of FDR -- July

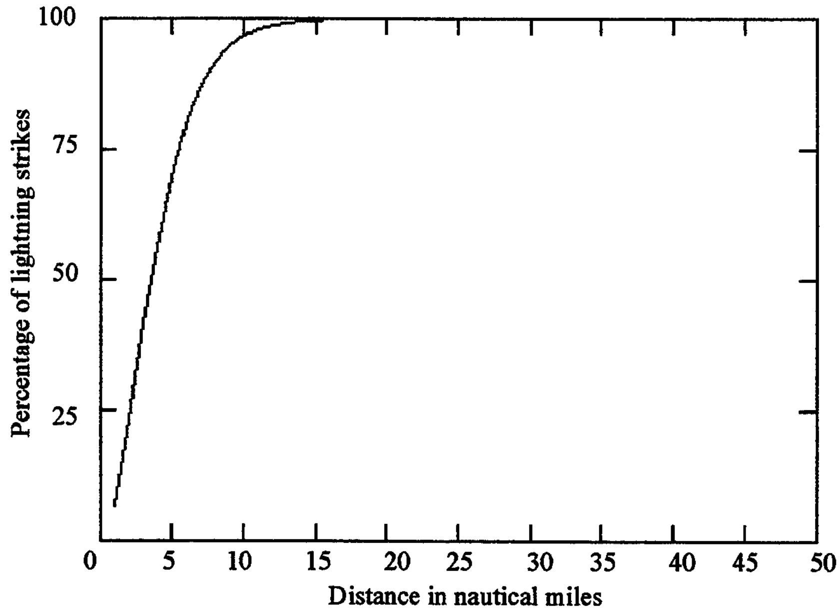

Figure 32 CDF of LIX -- July

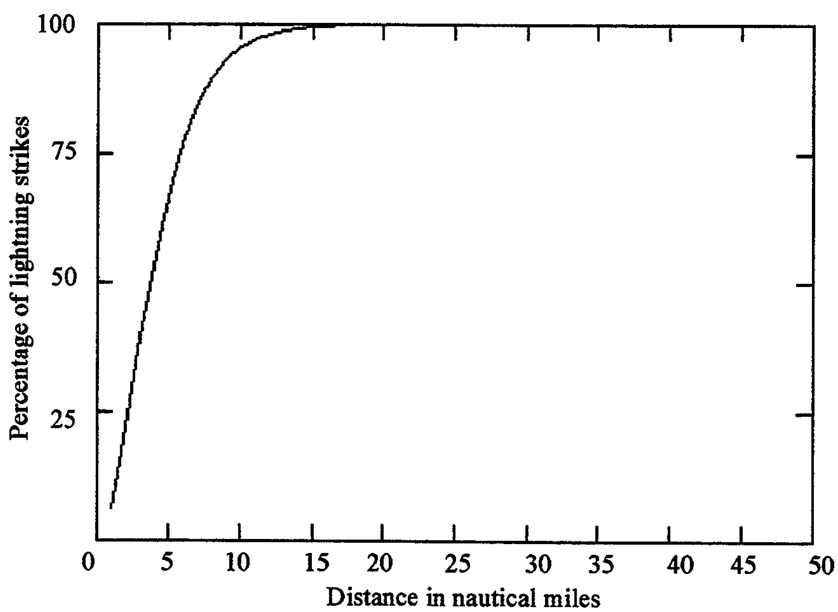

Figure 33 CDF of MOB -- July

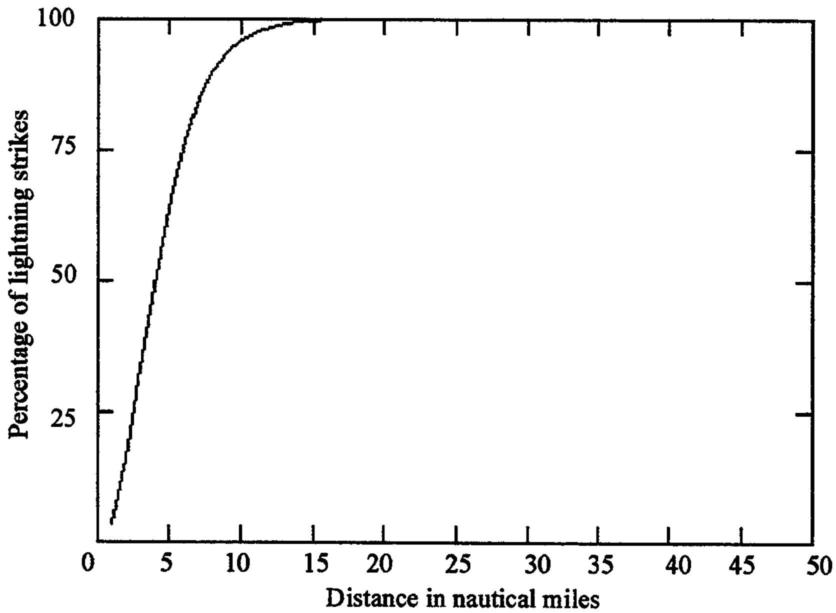

Figure 34 CDF of TLH -- July

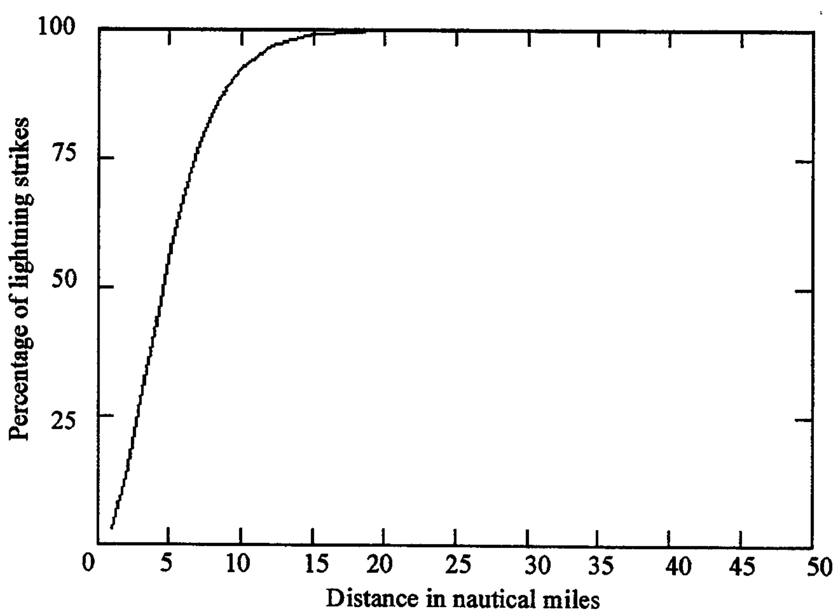

Figure 35 CDF of TLX -- July

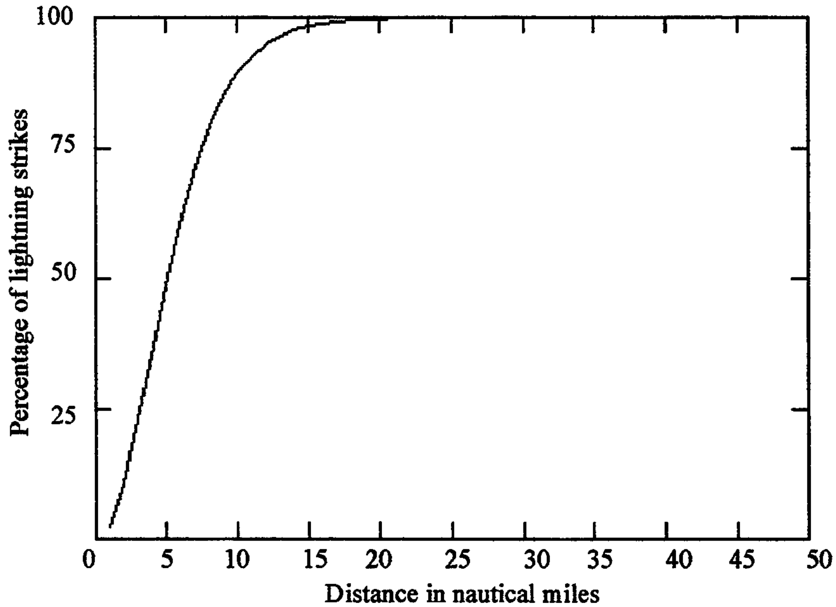

Figure 36 CDF of VNX -- July

Each of the radar sites have similar CDFs; however, differences exist, especially when the CDF curve approaches 100%. From these CDFs, 75% of all lightning strikes occur within 10 nm, with the exception of DYX in April. In July, about 90% of all lightning strikes occur within 10 nm. Nearly 100% of lightning strikes occur within 20 nm to 25 nm, with the exception of DYX in April.

k. Reflectivity Thresholds

As discussed in Chapter 2, both the WSR-88D SCIT and the NSSL SCIT contain seven different reflectivity thresholds, with a minimum reflectivity default of 30 dBZ. If these thresholds were decreased by 5 dBZ, more storm centroids would be identified and available to match with lightning strikes. This should lead to more accurate horizontal distance between storm cells and lightning strikes. This theory was tested using DYX in April, the site where the farthest distances occurred. Each of the seven reflectivity thresholds were lowered by 5 dBZ for the WSR-88D SCIT algorithm; however, the

minimum reflectivity threshold for the NSSL SCIT algorithm is 30 dBZ, so the reflectivity thresholds could not be lowered. After processing the algorithms, the same Fortran programs were used, as in Chapter 3. The same statistical procedures were also used. The mean horizontal distance was 7.84 nm, nearly 1 nm less than the horizontal distance with the default SCIT reflectivity parameters. Figure 37 is the histogram of distances for this threshold. This histogram is different from Figure 3. Many more lightning strikes are located within 0 to 10 nm, and less strikes occur at distances further away from the storm cell. The two histograms contain slightly different distributions. Figure 38 is the CDF of both the horizontal distances. The dashed line represents the CDF of the lower reflectivity thresholds, and the solid line is the CDF of the default reflectivity thresholds. The CDF also shows that different results and distributions occur when the default parameters are adjusted.

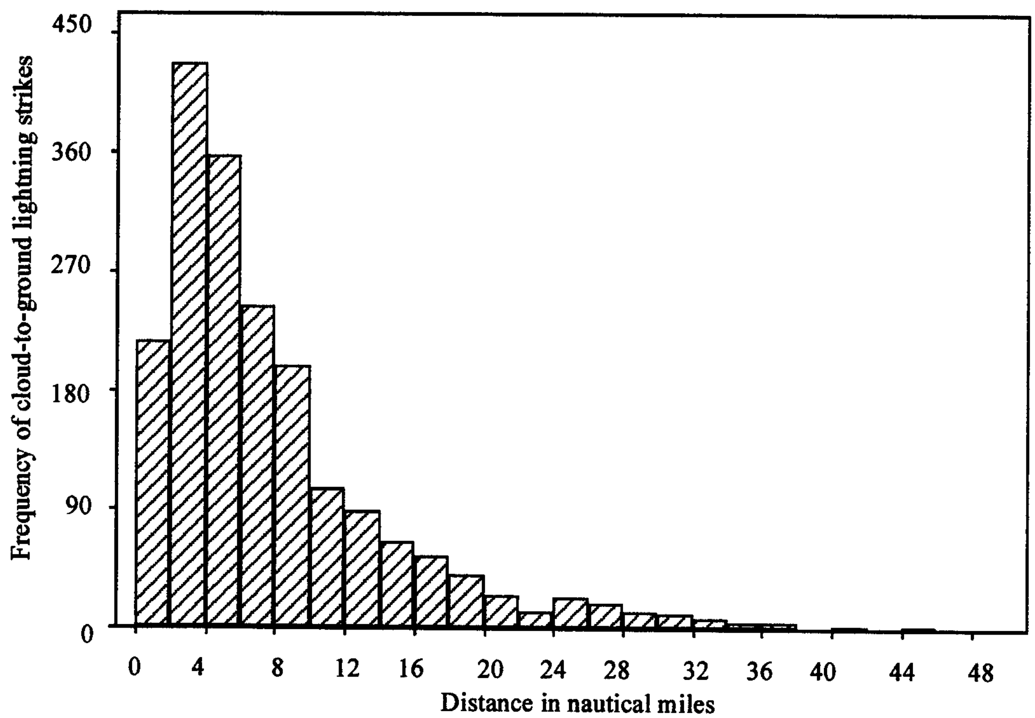

Figure 37 Histogram of all distances for DYX -- Lower Reflectivity Threshold

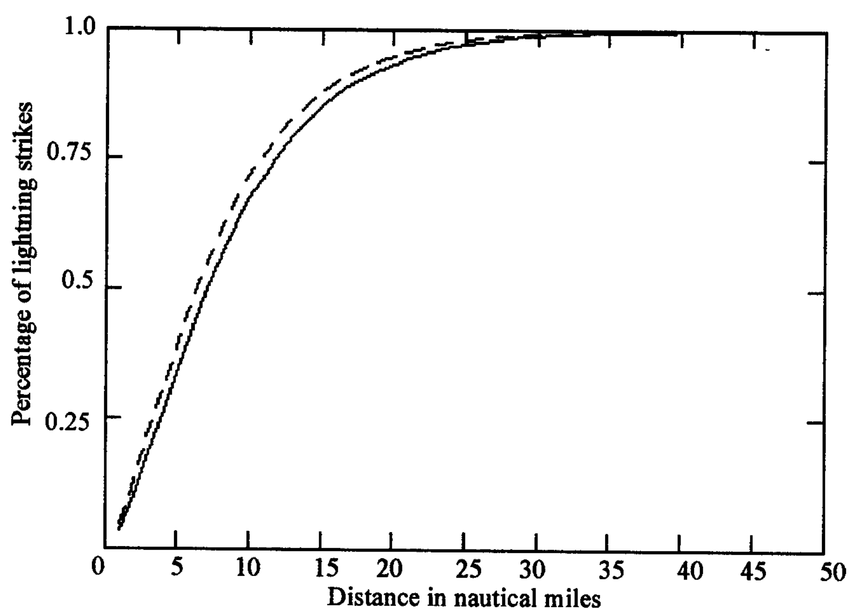

Figure 38 CDF of DYX -- April, Different Reflectivity Thresholds

5. Summary and Conclusions

a. Summary

The following is a summary of important results, with basic rules of thumb for forecasters in the two regions. From these results, suggesting "lightning within" criteria is difficult, since confusion would result having different lightning within criteria for every meteorological scenario.

The first comparison deals with lightning strike data and dBZ. In most cases, as the dBZ increases, the distance between the lightning strike and the centroid decrease. This statement should be used as a rule of thumb only, not requiring any special lightning within criteria.

Another rule of thumb for forecasters compares lightning strikes outside the area of the storm cell. In all cases, greater than 50% of all lightning strikes occur outside of storm cells. Average distances between the edge of the storm and lightning strikes range anywhere from just under two nm to over six and one-half nm.

Observing the number of lightning strikes behind the direction of storm motion, regional differences exist. Over 50% of lightning strikes occurred behind storm motion in the Gulf Coast in April, and the Southern Plains in July. Less than 50% of lightning strikes are behind storm motion in the Gulf Coast in July and the Southern Plains in April. No significant differences exist between the average distance of all lightning strikes and the distances of lightning strikes behind the storm.

The following is a regional comparison between lightning strikes and the height of the 0°C, -10°C, and -20°C lines. For this data, less than 1% of lighting strikes occur when the height of the maximum reflectivity is above -20°C, with the exception of the Southern Plains in April. Less than 5% of lighting strikes occur when the height of the storm cell is above -20°C, with the exception again being the Southern Plains in April. Vast percentages exist between the height of the 0°C line and the storm cell. Over 42% of lightning strikes are above the 0°C line in the Gulf Coast in April, diminishing to 27% in July. The Southern Plains contains the same monthly decrease, with over 33% in April, falling to just over 20% in July. More importantly, lightning does occur when the height of the maximum reflectivity is BELOW the 0°C line, and above the -20°C line. From this research, difficulty exists determining exact cut-off points comparing the height of the maximum reflectivity to the heights of the 0°C, -10°C, and -20°C isotherms. Mean distances decrease as the height of the maximum reflectivity increases.

The final comparison is between the all mean distances and mean distances with less than 100 lightning strikes per hour. Overall, little difference (less than 1 nm) exists between the two means, with the exception of DYX in April, TLH in April, VNX in April, MOB in July, and the Southern Plains in April. From the data, it is very difficult to determine any operationally significant impacts or rules of thumb.

Average distances for all stations in both April and July range anywhere from just under four nm to over eight and one-half nm. With the exception of DYX in April, the CDFs show that 75% of all lightning strikes were within 10 nm. In some cases, especially in July, 85% to over 90% of lightning strikes were within 10 nm. This thesis research

occasionally observed distances between storm cells and lightning strikes in excess of 40 nm; however, these strikes are rare, and would be difficult to enforce a "lightning within 40" criteria operationally.

b. Future Recommendations

This research is based on *only* TWO months worth of Level II archived data. Additional research is needed with more Level II archived data. A plethora of lightning data exists, but as more Level II data is archived, more analysis should be done. Additional research could dramatically change the percentage of lightning strikes compared to the heights of the isotherms. Many of these strikes were from only a few thunderstorms. As more data is archived and different storms are analyzed, different results would occur.

This thesis used default SCIT parameters. As discussed in Chapter 4, if the minimum reflectivity threshold is reduced to 25 dBZ, more centroids are available to match lightning strikes with. Level II data need to be lowered to this threshold for potentially more accurate distances. This threshold can be reduced for the WSR-88D algorithms only. The NSSL algorithms minimum reflectivity threshold is 30 dBZ. More effective research is possible if this threshold could be reduced. Additionally, each lightning strike needs to be verified on RADS. This way, the errors of developing storm cells can be avoided. This process would be extremely time consuming; however, much more accurate results could be obtained.

APPENDIX A

This appendix contains the dates and times of the Level II NEXRAD data used in this thesis.

Location	Start Date	Time (Z)	Stop Date	Time (Z)
KTLH	13-Apr	23:47	14-Apr	1:04
KTLH	15-Apr	11:48	15-Apr	12:17
KTLH	15-Apr	12:57	15-Apr	13:03
KTLH	30-Apr	0:49	30-Apr	1:59
KTLH	30-Apr	2:46	30-Apr	4:03
KTLH	23-Jul	14:51	23-Jul	16:01
KTLH	23-Jul	20:49	23-Jul	21:01
KTLH	24-Jul	17:51	24-Jul	19:01
KEVX	4-Jul	16:00	4-Jul	18:50
KEVX	4-Jul	18:50	4-Jul	19:02
KEVX	5-Jul	8:51	5-Jul	11:47
KEVX	5-Jul	11:47	5-Jul	12:04
KEVX	11-Jul	20:50	11-Jul	23:45
KEVX	11-Jul	23:45	12-Jul	0:03
KMOB	14-Apr	20:49	14-Apr	23:39
KMOB	14-Apr	23:40	15-Apr	2:35
KMOB	15-Apr	2:35	15-Apr	3:04
KMOB	18-Apr	8:46	18-Apr	11:36
KMOB	18-Apr	11:36	18-Apr	12:00
KMOB	12-Jul	17:59	12-Jul	20:03
KMOB	12-Jul	20:03	12-Jul	21:03
KMOB	13-Jul	18:19	13-Jul	21:02
KMOB	20-Jul	8:47	20-Jul	11:42
KMOB	20-Jul	11:43	20-Jul	12:00
KLIX	15-Apr	2:46	15-Apr	5:36
KLIX	15-Apr	5:36	15-Apr	8:31
KLIX	15-Apr	8:31	15-Apr	9:00
KLIX	23-Apr	5:48	23-Apr	6:35
KLIX	23-Apr	6:52	23-Apr	9:01
KLIX	13-Jul	20:46	13-Jul	23:42
KLIX	13-Jul	23:42	14-Jul	0:05
KLIX	17-Jul	20:49	17-Jul	23:44
KLIX	17-Jul	23:44	18-Jul	0:07
KLIX	23-Jul	20:47	23-Jul	23:42
KLIX	23-Jul	23:42	23-Jul	23:54

Location	Start Date	Time (Z)	Stop Date	Time (Z)
KDYX	22-Apr	5:48	22-Apr	7:04
KDYX	22-Apr	7:05	22-Apr	9:02
KDYX	22-Apr	9:24	22-Apr	11:55
KDYX	22-Apr	11:56	22-Apr	14:01
KDYX	24-Jul	11:46	24-Jul	14:42
KDYX	24-Jul	14:42	24-Jul	15:00
KDYX	26-Jul	23:47	27-Jul	2:43
KDYX	27-Jul	2:44	27-Jul	5:41
KDYX	27-Jul	5:41	27-Jul	6:05
KFDR	21-Apr	20:51	21-Apr	21:39
KFDR	21-Apr	21:39	22-Apr	0:34
KFDR	22-Apr	0:34	22-Apr	3:00
KFDR	22-Apr	15:47	22-Apr	18:41
KFDR	22-Apr	18:41	22-Apr	19:05
KFDR	9-Jul	2:47	9-Jul	5:39
KFDR	9-Jul	5:39	9-Jul	8:40
KFDR	9-Jul	8:40	9-Jul	9:03
KFDR	26-Jul	22:50	27-Jul	0:00
KTLX	8-Apr	8:53	8-Apr	12:07
KTLX	21-Apr	23:48	22-Apr	2:44
KTLX	22-Apr	2:45	22-Apr	5:40
KTLX	22-Apr	5:40	22-Apr	6:03
KTLX	22-Apr	8:56	22-Apr	11:52
KTLX	22-Apr	11:53	22-Apr	11:58
KTLX	29-Apr	20:55	30-Apr	0:10
KTLX	26-Jul	17:50	26-Jul	21:00
KVNX	14-Apr	3:18	14-Apr	6:05
KVNX	28-Apr	2:51	28-Apr	5:50
KVNX	28-Apr	5:50	28-Apr	8:49
KVNX	28-Apr	8:49	28-Apr	9:01
KVNX	26-Jul	5:49	26-Jul	8:44
KVNX	26-Jul	8:44	26-Jul	11:40
KVNX	26-Jul	11:40	26-Jul	12:03
KVNX	30-Jul	8:48	30-Jul	11:44
KVNX	30-Jul	11:44	30-Jul	12:02

APPENDIX B

This appendix contains examples of the fort.13, fort.14, and 3D.dat output files from the WATADS Algorithms.

fort.13:

SCIT_RTH	SCIT_LTH	SCIT_ATH
60	1.9	10.0
55	1.9	10.0
50	1.9	10.0
45	1.9	10.0
40	1.9	10.0
35	1.9	10.0
30	1.9	10.0

	DATE	041496	TIME	031849							
ID	AZM	RNG	MAXZ	POH	SHI	VIL	MASS	VOL	ARATIO	ZRAT	MAXAREA
1	283	91	55	100	57	37	651	241	2.51	1.02	32.8
2	303	103	59	100	39	35	717	264	3.36	1.00	62.3
3	279	105	56	80	34	34	607	272	3.26	1.04	85.2
4	30	43	50	90	25	15	116	189	5.45	1.39	12.4
5	276	90	50	80	17	10	140	126	1.29	1.09	23.1
6	294	94	53	50	11	9	278	116	1.16	1.00	19.1
7	123	192	46	100	9	12	383	705	0.68	1.02	0.0
8	267	127	47	30	4	11	294	408	1.70	1.04	65.3
9	297	102	58	20	3	22	305	79	1.72	1.00	22.3
10	261	116	45	30	2	10	144	236	1.87	1.00	43.9
11	314	99	42	0	0	3	34	60	0.94	1.02	10.6
12	335	117	45	0	0	7	199	435	1.27	1.00	67.6
13	312	118	47	0	0	7	171	344	0.95	1.00	56.2
14	130	240	47	999	0	17	387	394	1.39	1.00	29.4
15	270	104	40	0	0	3	19	97	1.83	1.21	0.0
16	28	63	40	0	0	2	24	140	1.92	1.05	0.0
17	36	101	40	0	0	2	29	142	0.93	1.08	0.0

18	126	199	39	0	0	5	54	253	1.27	1.05	0.0
19	32	133	38	0	0	4	102	545	1.74	1.00	0.0
20	27	93	36	0	0	2	14	78	1.53	1.00	0.0
21	326	105	36	0	0	1	38	319	0.53	1.00	0.0
22	313	88	36	0	0	1	21	153	0.48	1.03	0.0
23	333	88	35	0	0	1	30	245	0.47	1.06	0.0
24	28	149	34	0	0	2	98	846	0.82	1.00	0.0
25	24	168	33	0	0	2	85	823	0.64	1.00	0.0
26	332	76	33	0	0	1	10	97	0.57	1.03	0.0

SCIT_RTH	SCIT_LTH	SCIT_ATH
60	1.9	10.0
55	1.9	10.0
50	1.9	10.0
45	1.9	10.0
40	1.9	10.0
35	1.9	10.0
30	1.9	10.0

	DATE	041496	TIME	032450							
ID	AZM	RNG	MAXZ	POH	SHI	VIL	MASS	VOL	ARATIO	ZRAT	MAXAREA
1	284	84	56	90	51	22	383	140	2.66	1.06	11.8
2	288	90	58	100	49	39	1045	301	2.68	1.00	57.4
3	30	52	49	100	30	19	208	196	3.03	1.23	24.9
4	306	105	58	80	17	23	870	277	2.33	1.00	34.6
5	262	113	52	70	13	18	460	273	1.74	1.00	50.1
6	298	96	54	40	9	14	439	194	1.73	1.00	43.1
7	120	195	49	60	9	10	426	532	0.88	1.00	51.0
8	283	103	60	40	7	21	528	139	3.20	1.00	17.2
9	266	108	47	30	3	10	137	198	2.93	1.12	17.3
10	279	91	50	0	3	10	169	85	1.14	1.00	20.1
11	269	121	51	0	2	11	410	343	1.31	1.00	61.4
12	337	119	42	0	0	4	122	339	1.06	1.00	39.2
13	276	98	41	0	0	2	37	109	0.77	1.00	0.0
14	128	244	48	999	0	9	532	436	1.17	1.00	42.6
15	314	120	48	0	0	5	70	133	2.22	1.00	10.5
16	126	234	43	999	0	6	237	438	1.23	1.00	36.8
17	124	201	40	0	0	4	114	412	0.99	1.00	0.0
18	47	22	39	0	0	1	18	120	0.53	1.18	0.0

19	25	72	38	0	0	1	18	112	1.55	1.06	0.0
20	35	145	38	0	0	3	55	278	1.42	1.06	0.0
21	31	139	36	0	0	3	74	489	2.51	1.03	0.0
22	36	109	36	0	0	1	28	169	0.64	1.00	0.0
23	40	124	36	0	0	2	84	643	0.52	1.00	0.0
24	337	96	36	0	0	1	37	240	0.48	1.00	0.0
25	336	83	36	0	0	1	20	167	0.75	1.16	0.0
26	36	135	35	0	0	2	34	288	1.11	1.13	0.0
27	26	156	33	0	0	1	47	436	0.57	1.00	0.0
28	332	103	33	0	0	1	64	692	0.79	1.03	0.0
29	25	179	32	0	0	1	33	318	0.95	1.03	0.0
30	30	165	32	0	0	1	72	692	0.52	1.00	0.0

SCIT_RTH	SCIT_LTH	SCIT_ATH
60	1.9	10.0
55	1.9	10.0
50	1.9	10.0
45	1.9	10.0
40	1.9	10.0
35	1.9	10.0
30	1.9	10.0

	DATE	041496	TIME	033048							
ID	AZM	RNG	MAXZ	POH	SHI	VIL	MASS	VOL	ARATIO	ZRAT	MAXAREA
1	290	86	62	80	63	41	1879	335	3.09	1.00	100.5
2	266	106	54	100	36	27	476	209	3.13	1.00	39.8
3	30	59	51	80	12	16	224	148	2.03	1.09	27.1
4	272	113	52	60	11	18	363	335	3.14	1.00	27.4
5	118	199	46	40	6	9	300	417	1.00	1.00	41.5
6	310	107	55	40	5	18	578	275	2.24	1.00	41.2
7	302	100	57	20	4	20	391	281	3.26	1.00	15.4
8	287	99	57	20	3	16	392	175	1.69	1.00	54.0
9	39	134	42	0	1	3	73	361	1.12	1.31	0.0
10	317	123	43	0	0	3	68	277	0.85	1.00	21.5
11	35	117	42	0	0	2	31	117	1.10	1.00	12.1
12	340	124	42	0	0	4	85	201	1.46	1.00	31.9
13	122	204	40	0	0	4	160	513	0.84	1.00	0.0
14	273	91	40	0	0	2	54	217	0.79	1.00	0.0
15	121	214	39	0	0	3	88	368	1.14	1.00	0.0

16	331	115	38	0	0	1	199	802	0.19	1.00	0.0
17	34	154	38	0	0	3	48	174	0.94	1.00	0.0
18	339	92	37	0	0	2	36	282	2.33	1.19	0.0
19	45	128	37	0	0	2	29	126	1.12	1.00	0.0
20	352	78	37	0	0	1	30	157	0.46	1.00	0.0
21	63	47	37	0	0	1	11	74	0.81	1.09	0.0
22	44	31	37	0	0	2	42	239	0.81	1.00	0.0
23	27	82	36	0	0	1	20	151	0.41	1.00	0.0
24	338	103	36	0	0	2	100	901	1.73	1.00	0.0
25	99	26	36	0	0	2	24	188	0.87	1.03	0.0
26	31	148	35	0	0	2	75	645	1.18	1.03	0.0
27	48	85	35	0	0	1	12	79	0.78	1.03	0.0
28	46	114	33	0	0	1	27	243	0.62	1.00	0.0
29	93	38	32	0	0	1	13	131	1.13	1.00	0.0

SCIT_RTH	SCIT_LTH	SCIT_ATH
60	1.9	10.0
55	1.9	10.0
50	1.9	10.0
45	1.9	10.0
40	1.9	10.0
35	1.9	10.0
30	1.9	10.0

DATE 041496 TIME 033644

ID	AZM	RNG	MAXZ	POH	SHI	VIL	MASS	VOL	ARATIO	ZRAT	MAXAREA
1	294	82	57	100	97	35	1010	200	2.77	1.00	30.8
2	297	87	61	90	71	48	1767	396	3.54	1.00	118.5
3	268	100	53	90	48	18	446	203	1.06	1.00	31.1
4	30	68	55	100	13	21	368	185	2.50	1.08	38.9
5	115	203	47	100	12	11	343	489	0.82	1.00	25.0
6	275	107	53	50	10	13	359	193	2.40	1.00	31.7
7	120	208	46	0	4	6	187	364	1.00	1.00	0.0
8	315	110	51	0	2	12	274	256	3.04	1.00	42.3
9	290	97	53	0	1	11	436	164	0.76	1.00	50.9
10	306	102	56	0	0	15	275	185	3.75	1.00	35.7
11	281	85	41	0	0	2	42	99	0.52	1.00	0.0
12	42	41	40	0	0	3	49	237	1.14	1.11	0.0
13	341	130	39	0	0	2	85	376	0.53	1.00	0.0

14	38	143	39	0	0	4	75	316	1.27	1.03	0.0
15	44	136	39	0	0	2	118	458	0.62	1.00	0.0
16	344	97	39	0	0	3	43	203	1.44	1.00	0.0
17	83	30	38	0	0	2	25	151	1.36	1.00	0.0
18	36	162	37	0	0	2	72	435	1.23	1.00	0.0
19	354	86	37	0	0	2	18	102	1.13	1.06	0.0
20	59	56	37	0	0	2	31	197	1.42	1.00	0.0
21	47	94	37	0	0	2	31	135	0.82	1.00	0.0
22	341	106	36	0	0	1	153	1306	0.21	1.00	0.0
23	33	158	35	0	0	2	105	837	2.04	1.03	0.0
24	334	88	33	0	0	1	9	78	0.73	1.00	0.0

fort.14:

NO CELLS DETECTED PREVIOUSLY!

TIME	AVG_DIR	AVG_SPD	AVG_FE				
031849	0.0	0.0	999.0	NBR_NEW_STMS:			26

CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
1	283.2	90.7	999.0	999.0	55	6	0.0
2	303.3	102.6	999.0	999.0	59	2	0.0
3	279.4	105.4	999.0	999.0	56	5	0.0
4	30.3	43.2	999.0	999.0	50	8	0.0
5	276.4	89.5	999.0	999.0	50	7	0.0
6	293.5	94.0	999.0	999.0	53	5	0.0
7	123.1	192.0	999.0	999.0	46	7	0.0
8	267.0	127.5	999.0	999.0	47	4	0.0
9	297.2	101.9	999.0	999.0	58	2	0.0
10	260.8	116.3	999.0	999.0	45	6	0.0
11	313.6	99.1	999.0	999.0	42	5	0.0
12	334.6	116.5	999.0	999.0	45	2	0.0
13	312.1	118.5	999.0	999.0	47	2	0.0
14	129.9	240.4	999.0	999.0	47	6	0.0
15	270.4	104.0	999.0	999.0	40	5	0.0
16	27.6	63.4	999.0	999.0	40	2	0.0
17	36.4	101.2	999.0	999.0	40	7	0.0
18	126.4	198.7	999.0	999.0	39	8	0.0
19	32.4	132.7	999.0	999.0	38	7	0.0
20	27.2	93.1	999.0	999.0	36	1	0.0
21	326.1	104.7	999.0	999.0	36	2	0.0
22	312.6	87.7	999.0	999.0	36	6	0.0
23	333.2	88.4	999.0	999.0	35	6	0.0
24	27.8	149.5	999.0	999.0	34	6	0.0
25	24.1	168.1	999.0	999.0	33	6	0.0
26	331.7	76.0	999.0	999.0	33	6	0.0

CIRCLE_SIZE 11.9130

TIME	AVG_DIR	AVG_SPD	AVG_FE				
032450	999.0	999.0	4.9	NBR_NEW_STMS:			30

CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
27	283.6	83.9	999.0	999.0	56	5	0.0
1	287.6	90.0	200.9	19.1	58	1	3.9
4	29.6	51.6	206.0	23.4	49	6	5.1
2	305.7	104.7	187.8	13.2	58	2	3.2
10	262.5	113.4	212.5	12.2	52	2	1.3
9	298.3	96.4	279.0	16.2	54	3	4.4
7	120.3	195.1	229.7	27.3	49	4	5.9
3	283.5	102.6	212.6	22.0	60	2	4.3
28	266.0	108.5	999.0	999.0	47	4	0.0
5	279.0	91.1	166.1	12.3	50	4	4.5
8	268.9	121.1	235.2	21.0	51	2	3.7
12	337.1	119.4	216.5	16.4	42	4	2.3
15	276.0	97.7	215.5	32.3	41	5	7.9
14	127.8	243.9	239.3	27.2	48	6	5.9
13	314.4	120.4	201.6	14.6	48	2	2.6
29	126.0	234.2	999.0	999.0	43	6	0.0

18	124.0	201.1	231.6	24.3	40	4	4.8
30	47.0	21.9	999.0	999.0	39	7	0.0
16	25.1	72.2	188.0	25.7	38	2	6.9
31	35.1	144.7	999.0	999.0	38	8	0.0
32	30.6	138.7	999.0	999.0	36	5	0.0
17	36.0	109.4	210.5	22.9	36	4	4.7
33	39.7	124.4	999.0	999.0	36	8	0.0
34	337.4	96.0	999.0	999.0	36	5	0.0
23	336.3	83.3	292.2	19.1	36	7	6.2
19	35.6	135.2	285.1	21.8	35	7	6.5
24	26.4	156.2	179.2	21.1	33	3	6.0
21	331.6	102.6	250.4	28.5	33	5	6.7
25	24.6	178.7	213.0	29.6	32	7	7.0
35	30.4	165.0	999.0	999.0	32	6	0.0

CIRCLE_SIZE 11.8140

TIME	AVG_DIR	AVG_SPD	AVG_FE		
033048	222.1	18.6	3.3	NBR_NEW_STMS:	29

CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
1	290.0	86.4	219.0	15.6	62	1	4.7
28	266.1	105.8	260.8	7.4	54	2	4.9
4	29.7	59.2	208.1	22.3	51	2	1.0
8	271.8	112.7	235.0	24.9	52	2	2.7
7	117.6	198.8	230.0	28.0	46	4	0.5
2	310.3	107.0	197.7	18.7	55	2	4.4
9	302.0	99.6	224.7	12.3	57	2	9.7
3	286.9	98.9	219.0	20.8	57	2	1.9
33	39.1	134.0	210.9	27.1	42	7	3.4
13	317.0	123.4	199.5	16.1	43	2	1.1
17	35.0	116.8	205.8	22.1	42	2	1.5
12	339.7	123.7	213.2	17.8	42	2	1.2
18	121.9	204.2	233.6	23.1	40	4	1.0
36	272.7	91.5	222.1	999.0	40	3	0.0
37	121.0	213.6	222.1	999.0	39	5	0.0
38	330.5	115.3	222.1	999.0	38	2	0.0
31	34.4	153.6	203.5	25.6	38	8	3.6
34	339.1	91.6	305.1	14.7	37	7	8.0
39	45.2	127.6	222.1	999.0	37	6	0.0
40	352.2	77.6	222.1	999.0	37	5	0.0
41	62.5	47.0	222.1	999.0	37	5	0.0
30	44.4	31.5	218.5	27.0	37	5	3.1
16	26.6	82.4	203.0	26.5	36	1	5.0
21	337.7	103.2	245.8	29.4	36	5	1.8
42	98.6	26.5	222.1	999.0	36	6	0.0
32	31.4	148.1	223.1	26.9	35	6	3.0
43	48.3	85.0	222.1	999.0	35	7	0.0
44	46.3	114.2	222.1	999.0	33	8	0.0
45	92.8	38.4	222.1	999.0	32	7	0.0

CIRCLE_SIZE 11.7480

TIME	AVG_DIR	AVG_SPD	AVG_FE		
033644	220.9	20.0	3.1	NBR_NEW_STMS:	24

CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
1	293.9	81.7	229.3	16.7	57	5	3.1

46	296.6	87.4	220.9	999.0	61	1	0.0
28	267.9	100.3	244.0	12.5	53	7	4.2
4	30.4	67.6	210.6	22.6	55	2	1.1
7	114.8	202.9	229.9	28.5	47	4	0.5
8	275.4	106.6	232.2	25.4	53	4	1.5
18	119.8	208.4	235.7	23.3	46	5	1.0
2	315.1	109.7	201.4	21.6	51	2	3.1
3	290.0	96.7	220.1	19.3	53	1	1.6
9	306.2	102.2	207.3	15.3	56	2	4.6
36	280.6	85.1	214.1	38.7	41	4	6.8
30	42.3	40.9	216.9	26.9	40	7	0.6
12	341.5	129.7	206.8	18.5	39	2	2.4
33	38.0	142.8	206.6	26.4	39	7	1.5
39	43.7	135.7	201.9	24.6	39	7	3.1
47	344.4	97.0	220.9	999.0	39	5	0.0
42	83.4	30.0	206.3	23.2	38	2	2.3
31	36.0	161.5	223.6	23.8	37	6	6.3
40	354.4	85.9	194.1	24.8	37	4	4.1
41	59.0	55.5	220.4	25.4	37	6	1.9
43	47.4	93.5	218.3	24.2	37	8	1.6
21	341.1	106.0	241.1	26.2	36	4	4.7
32	32.7	157.9	227.3	27.9	35	6	1.6
34	333.9	87.7	9.3	13.9	33	4	10.9

CIRCLE_SIZE 11.7480

TIME	AVG_DIR	AVG_SPD	AVG_FE				
034240	219.0	21.4	3.3	NBR_NEW_STMS:			23

CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
46	300.1	84.2	240.1	17.4	60	4	2.9
28	273.7	95.2	225.0	17.8	58	1	8.0
4	30.4	77.5	211.0	23.7	53	1	1.9
7	111.9	207.9	229.7	29.3	48	5	1.3
39	42.4	144.6	202.5	25.6	43	7	0.7
48	262.7	97.8	219.0	999.0	42	6	0.0
30	38.4	49.7	212.0	26.4	42	6	2.7
36	289.0	82.6	210.5	36.7	55	1	2.2
2	317.7	113.6	200.0	21.4	43	4	2.1
49	323.2	111.3	219.0	999.0	48	2	0.0
9	311.2	105.7	202.2	18.3	52	2	4.3
50	300.6	90.9	219.0	999.0	59	1	0.0
8	283.9	106.7	219.1	27.6	48	3	11.1
51	286.8	92.6	219.0	999.0	45	1	0.0
42	73.3	37.1	212.7	24.5	39	7	2.1
40	355.4	93.2	190.6	22.9	38	3	1.7
33	39.0	149.0	214.0	23.3	38	5	5.4
21	345.9	105.2	243.4	25.1	38	5	2.9
32	35.0	166.1	235.6	27.9	37	6	4.5
43	45.9	101.1	213.3	23.3	37	5	1.6
41	55.4	63.4	216.3	24.8	36	7	1.4
52	16.6	79.4	219.0	999.0	35	1	0.0
53	47.1	112.8	219.0	999.0	33	6	0.0

CIRCLE_SIZE 11.7480

TIME	AVG_DIR	AVG_SPD	AVG_FE

	034836	216.4	23.8	3.4	NBR_NEW_STMS:		29
CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
28	277.1	91.9	221.0	19.0	60	6	0.9
50	304.8	87.5	239.9	20.8	62	1	3.4
7	109.5	213.5	230.1	29.5	49	5	0.6
4	32.5	89.1	214.0	25.3	50	1	4.4
48	267.2	90.7	219.0	28.7	47	6	1.8
30	39.6	59.2	213.8	26.3	46	7	2.3
39	42.0	151.4	205.3	23.8	43	8	2.7
8	290.9	100.8	216.5	30.2	41	7	4.3
49	326.1	115.8	196.3	20.2	42	4	3.0
54	25.4	91.8	216.4	999.0	41	6	0.0
52	20.5	97.2	217.3	52.6	41	6	10.2
36	293.7	80.2	212.0	31.5	54	1	6.2
55	300.2	97.0	216.4	999.0	46	1	0.0
40	357.2	102.3	191.9	23.9	41	2	1.7
41	53.2	73.1	216.8	25.8	41	2	1.3
56	347.2	122.4	216.4	999.0	39	2	0.0
43	45.3	108.5	213.8	22.5	39	2	1.0
57	3.7	106.8	216.4	999.0	39	5	0.0
21	347.2	112.5	237.5	22.9	38	6	8.3
58	339.0	106.4	216.4	999.0	38	5	0.0
59	45.5	95.8	216.4	999.0	38	8	0.0
33	37.5	160.8	211.2	24.9	37	6	5.0
60	340.0	114.0	216.4	999.0	37	2	0.0
61	317.6	156.0	216.4	999.0	37	3	0.0
42	67.7	44.5	216.0	24.3	37	5	1.5
53	47.0	118.9	223.9	17.2	35	6	2.5
62	0.3	61.3	216.4	999.0	34	7	0.0
63	71.1	64.8	216.4	999.0	34	7	0.0
64	263.2	110.7	216.4	999.0	33	5	0.0

CIRCLE_SIZE 11.8470

TIME	AVG_DIR	AVG_SPD	AVG_FE

	035435	216.4	25.6	2.9	NBR_NEW_STMS:		23
CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
28	281.4	86.4	221.3	20.1	63	1	2.1
50	310.1	89.0	222.5	21.1	61	4	4.5
48	270.9	84.1	223.1	26.3	54	5	2.2
4	32.9	99.5	216.7	27.3	51	1	1.4
30	38.5	68.5	214.0	26.2	48	8	0.4
7	107.0	219.1	230.2	30.1	47	5	0.5
59	43.5	104.8	203.1	26.9	43	7	2.2
65	23.4	104.3	216.4	999.0	43	7	0.0
49	326.1	120.4	177.4	15.1	46	2	5.5
57	4.3	113.5	193.7	18.8	41	4	4.0
66	332.3	121.5	216.4	999.0	41	2	0.0
60	347.5	119.1	235.3	44.8	40	2	8.0
43	43.9	116.1	212.1	22.3	40	2	1.2
33	39.3	171.9	216.4	26.0	40	6	6.9
42	61.7	52.7	216.0	24.7	40	3	1.0
54	26.7	100.4	220.3	24.8	40	5	0.7
39	40.4	161.7	204.2	24.8	38	6	2.9
62	2.4	70.3	196.3	25.8	38	6	3.2
67	121.1	201.8	216.4	999.0	37	4	0.0
40	358.3	112.1	191.6	24.9	36	2	1.5

53	45.4	127.3	211.9	20.9	35	7	3.9
41	53.9	85.6	222.3	27.5	35	10	5.1
63	66.8	72.0	213.5	24.8	33	5	0.5

CIRCLE_SIZE 11.7150

TIME	AVG_DIR	AVG_SPD	AVG_FE		
040030	214.1	24.5	3.0	NBR_NEW_STMS:	31

CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
28	286.9	85.0	217.1	22.8	65	1	2.6
68	312.0	80.8	214.1	999.0	57	3	0.0
50	314.2	92.5	212.5	20.6	64	1	3.7
48	278.7	80.5	216.5	27.7	58	5	4.4
7	104.9	224.5	230.1	30.1	50	5	0.8
4	32.8	110.4	217.1	29.2	52	2	1.5
30	38.1	78.5	214.0	26.4	50	5	0.7
69	97.1	199.8	214.1	999.0	45	8	0.0
65	21.9	113.7	184.9	27.9	46	6	4.8
70	297.3	86.9	214.1	999.0	47	4	0.0
71	263.4	95.2	214.1	999.0	43	5	0.0
72	322.2	103.1	214.1	999.0	43	5	0.0
42	58.3	61.8	216.5	25.2	44	2	1.1
66	334.5	127.7	190.7	22.0	42	2	3.5
57	5.3	122.4	196.3	22.2	42	2	2.6
73	319.2	117.4	214.1	999.0	42	2	0.0
74	350.2	128.0	214.1	999.0	42	2	0.0
39	39.3	172.7	203.7	26.2	39	3	2.7
67	118.7	205.5	232.6	27.0	39	4	3.1
62	4.4	79.9	197.3	27.0	39	2	0.9
75	113.3	187.7	214.1	999.0	39	7	0.0
43	43.8	128.1	213.9	23.8	38	2	4.5
41	50.6	93.0	220.4	27.4	38	8	4.2
76	331.2	100.8	214.1	999.0	38	5	0.0
77	338.3	123.9	214.1	999.0	37	4	0.0
78	342.7	124.6	214.1	999.0	37	4	0.0
60	352.2	123.3	236.0	37.8	36	4	5.1
53	44.2	139.5	211.4	25.5	36	7	5.0
63	61.9	77.4	204.2	23.9	35	2	2.9
79	47.4	138.2	214.1	999.0	34	7	0.0
80	51.7	114.1	214.1	999.0	33	8	0.0

CIRCLE_SIZE 11.7480

TIME	AVG_DIR	AVG_SPD	AVG_FE		
040626	213.0	25.5	3.6	NBR_NEW_STMS:	27

CID	AZ	RNG	DIR	SPD	MAXZ	HMAXZ	FERR
68	315.7	81.3	218.5	14.9	61	3	3.8
48	281.9	78.0	215.4	25.4	62	1	4.8
28	291.8	82.0	215.9	22.9	64	1	0.8
30	35.7	88.3	212.0	26.8	53	7	3.0
4	33.3	120.0	217.3	29.9	53	2	0.8
70	301.0	88.7	191.3	16.8	53	1	4.2
50	319.5	96.7	207.8	21.9	63	1	2.9
65	22.5	122.7	197.1	26.1	47	2	4.3
69	95.4	205.3	228.3	23.3	46	4	2.4
71	265.3	91.9	220.9	12.7	45	3	4.6

42	54.9	69.5	216.8	25.6	43	2	1.1
72	326.2	108.0	200.5	25.0	41	5	2.0
81	307.6	77.7	213.0	999.0	55	1	0.0
82	273.3	85.3	213.0	999.0	48	3	0.0
66	335.2	132.7	184.0	18.3	42	2	3.1
73	322.5	122.6	193.6	24.0	42	2	3.0
62	5.5	88.3	197.0	26.2	40	1	1.1
74	354.8	135.7	227.0	36.9	40	2	4.8
79	45.6	147.8	201.9	29.6	40	8	2.4
76	334.5	109.3	187.7	29.0	40	5	4.4
53	41.4	151.6	206.2	29.0	40	8	6.3
41	49.1	103.0	219.2	27.9	39	9	1.0
83	63.8	58.4	213.0	999.0	39	7	0.0
60	357.1	120.9	246.4	32.9	38	4	8.9
77	340.2	136.9	177.5	38.4	37	5	8.2
43	45.2	134.2	218.6	23.6	37	7	5.2
84	325.5	77.4	213.0	999.0	37	4	0.0

CIRCLE_SIZE 11.6820

3D.dat:

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NO CELLS DETECTED PREVIOUSLY!

     TIME    AVG_DIR AVG_SPD  AVG_FE
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     031849    0.0      0.0    999.0   NBR_NEW_STMS:          27
 CID AZ/RAN   BASE   TOP  CELL BASED VIL MAX REF HEIGHT
     DEG/NM    KFT  KFT       KG/M**2         DBZ      KFT
  1 304./ 55.    5.2 27.3          38.          59        5.2
  2 279./ 57.    5.5 26.9          38.          56       16.5
  3 283./ 49.    4.6 31.2          38.          55       19.0
  4 294./ 51.   15.0 23.3           9.          53       15.0
  5  30./ 23.    1.3 35.4          18.          51       24.7
  6 297./ 55.    5.2 15.7          23.          58        5.2
  7 276./ 48.   14.6 22.9          10.          50       22.9
  8 123./104.   13.2 24.5          12.          46       24.5
  9 267./ 69.    7.1 27.6          12.          47       14.3
 10 261./ 63.    6.4 29.4          11.          46       13.0
 11 312./ 64.    6.3 19.5           8.          47        6.3
 12 314./ 53.   10.5 16.2           3.          43       16.2
 13 335./ 63.    6.2 25.6           7.          45        6.2
 14 270./ 56.    5.4 16.5           3.          41       16.5
 15  28./ 34.    2.4 14.1           2.          42        6.2
 16 130./130.   19.0 33.0          17.          47       19.0
 17 272./ 64.    6.5 12.7           3.          40        6.5
 18  36./ 55.   16.2 21.9           2.          40       21.9
 19 126./107.   13.9 25.6           5.          39       25.6
 20  32./ 72.    7.0 30.7           4.          38       22.7
 21  27./ 50.    4.3 16.1           2.          37        4.3
 22 333./ 48.   13.9 18.8           1.          37       18.8
 23 326./ 57.    5.6 10.9           1.          36        5.6
 24 313./ 47.   13.9 18.5           1.          36       18.5
 25  24./ 91.   10.6 21.0           2.          34       21.0
 26  28./ 81.    8.6 26.4           3.          34       18.2
 27 332./ 41.   16.0 19.4           1.          34       19.4
 CIRCLE_SIZE    10.8300

     TIME    AVG_DIR AVG_SPD  AVG_FE
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     032450   999.0   999.0      4.6   NBR_NEW_STMS:          30
 CID AZ/RAN   BASE   TOP  CELL BASED VIL MAX REF HEIGHT
     DEG/NM    KFT  KFT       KG/M**2         DBZ      KFT
  3 288./ 48.    4.5 31.3          42.          58        4.5
 28 284./ 45.   13.2 29.1          23.          57       17.9
  6 298./ 52.   10.4 24.8          16.          54       15.1
  1 306./ 57.    5.3 27.9          25.          59        5.3
  2 284./ 55.    5.2 26.2          22.          61        5.2
  5  30./ 28.    1.7 29.6          20.          49       18.5
 10 262./ 61.    6.0 28.8          18.          52        6.0
  8 120./105.   13.5 25.2          10.          49       13.5
  7 279./ 49.    4.5 13.9          12.          51       13.9
 29 266./ 59.    5.6 28.2          12.          48       12.1
  9 269./ 65.    6.6 25.6          12.          51        6.6
 11 314./ 65.    6.5 19.8           5.          48        6.5
 13 337./ 64.    6.3 20.2           4.          42       13.4
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14	276./ 53.	15.6	20.9	2.	41	15.6
16	128./132.	19.5	33.6	9.	48	19.5
30	126./126.	18.2	32.1	6.	43	18.2
19	124./109.	14.2	26.1	4.	40	14.2
15	25./ 39.	3.0	12.3	2.	39	7.6
31	35./ 78.	16.5	32.8	3.	39	24.8
32	47./ 12.	18.5	23.7	1.	39	23.7
22	337./ 52.	15.3	20.5	1.	37	15.3
33	31./ 75.	7.8	32.2	3.	36	16.8
18	36./ 59.	11.9	18.0	1.	36	18.0
34	40./ 67.	20.6	27.4	2.	36	27.4
27	336./ 45.	13.5	21.4	1.	36	21.4
20	36./ 73.	15.3	30.5	2.	35	22.8
25	25./ 96.	11.7	22.5	1.	33	22.5
26	26./ 84.	9.5	19.3	1.	33	9.5
23	332./ 55.	11.1	15.8	1.	33	15.8
35	30./ 89.	20.0	28.9	1.	33	20.0

CIRCLE_SIZE 10.7400

TIME	AVG_DIR	AVG_SPD	AVG_FE		
033048	216.6	19.8	2.9	NBR_NEW_STMS:	29

CID	AZ/RAN	BASE	TOP	CELL BASED VIL	MAX REF	HEIGHT
	DEG/NM	KFT	KFT	KG/M**2	DBZ	KFT
28	290./ 46.	4.3	27.1	43.	64	4.3
29	266./ 57.	5.5	28.0	34.	56	5.5
5	30./ 32.	2.2	21.7	19.	51	15.8
9	272./ 61.	5.9	30.5	19.	53	5.9
6	302./ 54.	5.0	26.2	21.	58	5.0
1	310./ 58.	5.5	28.9	20.	56	5.5
2	287./ 53.	5.1	15.2	16.	57	5.1
8	118./107.	13.9	25.8	9.	46	13.9
34	39./ 72.	15.1	30.0	3.	42	22.5
11	317./ 67.	6.7	14.0	3.	43	6.7
18	35./ 63.	6.1	13.2	3.	43	6.1
13	340./ 67.	6.6	21.9	4.	42	6.6
36	273./ 49.	9.8	18.4	2.	41	9.8
19	122./110.	14.6	26.7	4.	40	14.6
37	121./115.	15.7	28.5	3.	39	15.7
38	352./ 42.	16.4	20.4	2.	39	16.4
39	331./ 62.	6.1	12.1	1.	38	6.1
31	34./ 83.	18.1	26.7	3.	38	26.7
40	45./ 69.	21.2	28.1	2.	38	21.2
32	44./ 17.	18.0	26.3	3.	38	26.3
41	99./ 14.	15.2	21.3	2.	38	21.3
27	339./ 49.	9.8	24.1	2.	37	24.1
42	63./ 25.	11.8	17.2	1.	37	17.2
15	27./ 44.	3.7	8.8	1.	36	3.7
33	31./ 80.	8.8	18.2	2.	36	18.2
23	338./ 56.	11.1	22.6	2.	36	16.8
43	48./ 46.	18.0	22.7	1.	36	22.7
44	46./ 62.	24.9	30.8	1.	33	24.9
45	93./ 21.	13.6	21.7	1.	32	21.7

CIRCLE_SIZE 10.6800

TIME	AVG_DIR	AVG_SPD	AVG_FE

033644	215.0	21.5	2.6	NBR_NEW_STMS:	24

CID	AZ/RAN DEG/NM	BASE KFT	TOP KFT	CELL BASED VIL KG/M**2	MAX REF DBZ	HEIGHT KFT
46	294./ 44.	12.8	29.1	35.	59	17.4
28	297./ 47.	4.3	31.6	28.	62	4.3
29	268./ 54.	16.2	26.5	19.	54	16.2
9	275./ 58.	11.6	28.7	14.	53	11.6
5	30./ 36.	2.7	26.6	24.	55	6.7
8	115./110.	14.4	26.5	11.	47	14.4
6	306./ 55.	5.1	27.8	15.	57	5.1
1	315./ 59.	5.6	30.2	13.	52	5.6
19	120./113.	15.1	27.3	7.	46	15.1
2	290./ 52.	4.7	14.8	11.	53	4.7
36	281./ 46.	13.4	17.5	2.	43	13.4
32	42./ 22.	14.5	23.5	4.	42	23.5
13	341./ 70.	7.2	15.4	2.	39	7.2
34	38./ 77.	16.5	32.3	4.	39	24.1
38	354./ 46.	8.8	18.4	2.	39	13.6
40	44./ 73.	22.7	30.4	2.	39	22.7
27	344./ 52.	15.5	25.9	3.	39	15.5
43	47./ 50.	19.9	25.4	2.	39	19.9
41	83./ 16.	7.1	18.3	2.	39	7.1
42	59./ 30.	7.8	21.2	3.	38	21.2
31	36./ 87.	19.1	28.3	2.	37	19.1
33	33./ 85.	9.8	26.6	3.	36	26.6
23	341./ 57.	11.5	18.1	1.	36	11.5
47	334./ 47.	13.8	18.6	1.	34	13.8

CIRCLE_SIZE 10.6800

TIME	AVG_DIR	AVG_SPD	AVG_FE		
034240	215.4	23.5	2.8	NBR_NEW_STMS:	22

CID	AZ/RAN DEG/NM	BASE KFT	TOP KFT	CELL BASED VIL KG/M**2	MAX REF DBZ	HEIGHT KFT
46	300./ 45.	8.7	30.0	47.	62	13.4
29	274./ 51.	4.8	32.0	47.	59	10.2
8	112./112.	15.0	27.4	12.	48	15.0
5	30./ 42.	3.3	30.2	22.	54	3.3
36	289./ 45.	3.8	12.4	13.	57	3.8
40	42./ 78.	24.4	33.0	4.	43	24.4
6	311./ 57.	5.3	23.2	10.	53	5.3
28	301./ 49.	4.3	15.2	11.	60	4.3
48	323./ 60.	5.7	25.0	7.	48	5.7
1	318./ 61.	12.5	18.9	3.	43	12.5
41	73./ 20.	0.9	23.0	4.	42	23.0
49	263./ 53.	10.8	20.6	3.	42	20.6
32	38./ 27.	4.4	18.3	4.	42	18.3
50	287./ 50.	4.5	8.8	3.	45	4.5
38	355./ 50.	4.4	15.1	3.	41	4.4
34	39./ 80.	8.8	25.9	4.	40	17.5
27	346./ 57.	11.4	28.2	3.	39	17.0
43	46./ 54.	4.7	22.2	3.	38	16.2
42	56./ 34.	2.2	24.0	4.	38	24.0
33	33./ 90.	10.6	28.5	3.	37	20.2
51	17./ 43.	3.5	8.4	1.	36	3.5
52	47./ 61.	18.4	24.2	1.	34	18.4

CIRCLE_SIZE 10.6800

TIME	AVG_DIR	AVG_SPD	AVG_FE		
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034836	208.3	24.2	3.5	NBR_NEW_STMS:	31

CID	AZ/RAN DEG/NM	BASE KFT	TOP KFT	CELL BASED VIL KG/M**2	MAX REF DBZ	HEIGHT KFT
29	277./ 50.	4.6	28.1	46.	61	14.0
46	305./ 47.	4.3	30.2	47.	62	4.3
8	110./115.	15.7	28.3	13.	49	15.7
5	32./ 48.	4.0	33.7	20.	50	4.0
49	267./ 49.	4.8	23.7	10.	48	19.1
32	40./ 32.	2.0	21.8	8.	46	21.8
36	294./ 43.	3.7	11.8	10.	54	3.7
40	42./ 82.	9.2	25.9	6.	45	25.9
48	326./ 63.	12.7	26.3	4.	44	12.7
50	291./ 54.	21.7	27.0	2.	41	21.7
53	25./ 50.	19.6	23.7	2.	41	19.6
51	21./ 52.	15.5	26.1	4.	42	20.9
42	53./ 38.	2.8	20.4	3.	41	7.3
28	300./ 52.	4.7	10.3	3.	46	4.7
38	357./ 55.	5.0	16.9	3.	41	5.0
41	68./ 24.	1.2	26.4	4.	40	16.8
43	45./ 59.	5.4	18.0	3.	40	5.4
54	4./ 58.	17.3	23.0	2.	40	17.3
55	347./ 66.	6.6	14.1	2.	39	6.6
27	347./ 61.	5.6	24.6	4.	39	12.5
56	45./ 52.	20.6	25.6	2.	39	25.6
34	37./ 87.	9.9	28.9	4.	38	9.9
57	339./ 57.	11.3	17.5	1.	38	17.5
58	340./ 62.	5.9	13.1	1.	37	5.9
59	318./ 84.	9.6	18.5	2.	37	9.6
33	33./ 95.	11.6	21.9	2.	35	11.6
52	47./ 64.	19.5	27.5	1.	35	19.5
60	263./ 60.	12.2	17.8	1.	34	17.8
61	0./ 33.	12.3	22.3	2.	34	22.3
62	71./ 35.	16.6	23.8	1.	34	23.8
63	99./104.	13.3	24.5	2.	33	24.5

CIRCLE_SIZE 10.7700

TIME	AVG_DIR	AVG_SPD	AVG_FE		
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035435	207.7	24.7	2.5	NBR_NEW_STMS:	27

CID	AZ/RAN DEG/NM	BASE KFT	TOP KFT	CELL BASED VIL KG/M**2	MAX REF DBZ	HEIGHT KFT
29	282./ 46.	4.3	28.9	50.	64	4.3
46	311./ 48.	4.3	30.9	50.	62	4.3
49	271./ 45.	4.3	28.5	36.	56	17.8
8	107./118.	16.3	29.4	12.	49	16.3
5	33./ 54.	4.7	27.6	19.	52	4.7
32	38./ 37.	2.6	25.0	15.	49	25.0
56	43./ 57.	22.7	28.4	2.	43	22.7
64	23./ 56.	16.8	28.3	4.	43	22.7
48	326./ 65.	6.5	20.3	6.	46	6.5
63	98./106.	13.7	24.8	5.	42	24.8
53	27./ 54.	16.1	21.5	2.	41	16.1

65	332./ 66.	6.5	19.9	5.	42	6.5
54	4./ 61.	5.8	18.9	4.	41	12.7
27	347./ 64.	6.3	20.2	4.	40	6.3
41	62./ 28.	1.6	19.6	4.	40	11.1
43	44./ 63.	6.1	13.3	2.	40	6.1
34	39./ 93.	21.0	31.0	3.	40	21.0
66	115./103.	13.1	24.4	3.	39	24.4
42	50./ 43.	3.5	13.3	2.	38	8.4
38	358./ 61.	5.7	25.0	3.	38	5.7
40	40./ 87.	10.1	28.0	4.	38	28.0
61	2./ 38.	6.9	18.9	2.	38	18.9
67	121./109.	14.3	26.3	3.	37	14.3
52	45./ 69.	7.0	21.8	2.	36	21.8
68	54./ 46.	13.2	31.8	3.	36	31.8
33	33./100.	12.5	23.3	2.	34	12.5
62	67./ 39.	14.9	19.4	1.	34	14.9

CIRCLE_SIZE 10.6500

TIME	AVG_DIR	AVG_SPD	AVG_FE
040030	210.5	23.1	2.7

NBR_NEW_STMS: 31

CID	AZ/RAN DEG/NM	BASE KFT	TOP KFT	CELL BASED VIL KG/M**2	MAX REF DBZ	HEIGHT KFT
29	288./ 45.	4.0	29.3	46.	65	4.0
46	315./ 50.	4.4	30.6	46.	65	4.4
69	312./ 44.	8.7	27.1	40.	57	16.4
49	279./ 43.	3.9	26.0	39.	58	16.5
8	105./121.	17.0	30.6	12.	50	17.0
5	33./ 60.	5.5	30.4	21.	52	5.5
32	38./ 42.	3.2	28.4	18.	51	16.7
64	22./ 61.	5.9	31.1	13.	46	25.1
70	297./ 47.	13.8	30.3	6.	47	13.8
63	97./108.	14.1	25.8	7.	45	25.8
71	322./ 56.	16.6	27.7	3.	43	16.6
72	263./ 51.	4.9	22.7	7.	43	15.0
54	5./ 66.	6.5	20.5	4.	44	6.5
65	334./ 69.	7.0	21.7	4.	42	7.0
27	350./ 69.	6.8	21.9	4.	42	6.8
41	58./ 33.	2.2	22.8	6.	45	5.9
73	319./ 63.	6.3	12.9	2.	42	6.3
68	50./ 49.	4.1	25.5	4.	40	20.4
40	39./ 93.	11.4	29.6	4.	39	11.4
67	119./111.	14.7	26.9	4.	39	14.7
61	4./ 43.	3.4	17.4	2.	39	8.1
66	113./101.	12.2	23.9	3.	39	23.9
74	338./ 67.	6.6	20.9	3.	38	6.6
43	44./ 69.	7.1	14.5	2.	38	7.1
75	331./ 54.	16.2	21.5	1.	38	16.2
76	352./ 67.	6.9	20.0	2.	37	13.3
77	343./ 67.	14.0	20.8	1.	37	14.0
62	62./ 42.	7.9	12.4	1.	37	7.9
52	44./ 75.	16.1	24.4	2.	36	24.4
78	47./ 75.	23.3	30.8	1.	35	23.3
79	52./ 62.	18.6	24.8	1.	33	24.8

CIRCLE_SIZE 10.6800

APPENDIX C

This appendix contains the Fortran program that sorts lightning strikes for the eight radar locations, within a 60nm radius of each site. The code in this program is not ANSI-standard Fortran.

```
C23456789012345678901234567890123456789012345678901234567890123456789012

C THIS PROGRAM READS IN ALL LIGHTNING STRIKES FOR AND KEEPS THE STRIKES
c WITHIN 60NM OF THE SPECIFIC RADAR SITE.

      PROGRAM PROG1

C DEFINING VARIABLES

      REAL PI,MOBLAT,MOBLON,LIXLAT,LIXLON,LAT,LON,MILRNG
      INTEGER YR,MO,DAY,HR,MIN,SEC

      PARAMETER(R=6378.0)
      PARAMETER(MOBLAT=30.680,MOBLON=-88.240)
      PARAMETER(LIXLAT=30.337,LIXLON=-89.826)
      PARAMETER(EVXLAT=30.565,EVXLON=-85.922)
      PARAMETER(TLHLAT=30.400,TLHLON=-84.329)
      PARAMETER(DYXLAT=32.538,DYXLON=-99.254)
      PARAMETER(FDRLAT=34.362,FDRLON=-98.977)
      PARAMETER(TLXLAT=35.333,TLXLON=-97.278)
      PARAMETER(VNXLAT=36.741,VNXLON=-98.128)
      PARAMETER(MILRNG=60.0)
      PI=ATAN(1.0)*4.0
      RNG=MILRNG*1.8
      PRINT*,RNG

C OPEN THE FILES

      OPEN(UNIT=10, FILE='APR.DAT', STATUS='OLD')
      OPEN(20,FILE='MOBAPR',STATUS='NEW')
      OPEN(30,FILE='LIXAPR',STATUS='NEW')
      OPEN(40,FILE='EVXAPR',STATUS='NEW')
      OPEN(50,FILE='TLHAPR',STATUS='NEW')
      OPEN(60,FILE='DYXAPR',STATUS='NEW')
      OPEN(70,FILE='FDRAPR',STATUS='NEW')
      OPEN(80,FILE='TLXAPR',STATUS='NEW')
      OPEN(90,FILE='VNXAPR',STATUS='NEW')
1     READ(10,*,END=999)YR,MO,DAY,HR,MIN,SEC,LAT,LON

C USING SPHERCIAL COORDINATES, THE FOLLOWING ARE EQUATIONS THAT COMPUTE
C THE DISTANCE BETWEEN TWO LATITUDES AND LONGITUDES.  FOR THIS CASE, WE
C ARE COMPUTING THE DISTANCE BETWEEN THE RDA AND THE LIGHTNING STRIKE.

      DMOB=R*(ACOS(SIN(MOBLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (MOBLAT*(PI/180))*COS(LAT*(PI/180))*COS((MOBLON-LON)*(PI/180))))
```

```
      IF(DMOB .LT. RNG) THEN
        WRITE(20,25)YR,MO,DAY,HR,MIN,SEC,LAT,LON
25        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF

      DLIX=R*(ACOS(SIN(LIXLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (LIXLAT*(PI/180))*COS(LAT*(PI/180))*COS((LIXLON-LON)*(PI/180))))
      IF(DLIX .LT. RNG) THEN
        WRITE(30,35)YR,MO,DAY,HR,MIN,SEC,LAT,LON
35        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF

      DEVX=R*(ACOS(SIN(EVXLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (EVXLAT*(PI/180))*COS(LAT*(PI/180))*COS((EVXLON-LON)*(PI/180))))
      IF(DEVX .LT. RNG) THEN
        WRITE(40,45)YR,MO,DAY,HR,MIN,SEC,LAT,LON
45        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF

      DTLH=R*(ACOS(SIN(TLHLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (TLHLAT*(PI/180))*COS(LAT*(PI/180))*COS((TLHLON-LON)*(PI/180))))
      IF(DTLH .LT. RNG) THEN
        WRITE(50,55)YR,MO,DAY,HR,MIN,SEC,LAT,LON
55        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF

      DDYX=R*(ACOS(SIN(DYXLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (DYXLAT*(PI/180))*COS(LAT*(PI/180))*COS((DYXLON-LON)*(PI/180))))
      IF(DDYX .LT. RNG) THEN
        WRITE(60,65)YR,MO,DAY,HR,MIN,SEC,LAT,LON
65        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF

      DFDR=R*(ACOS(SIN(FDRLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (FDRLAT*(PI/180))*COS(LAT*(PI/180))*COS((FDRLON-LON)*(PI/180))))
      IF(DFDR .LT. RNG) THEN
        WRITE(70,75)YR,MO,DAY,HR,MIN,SEC,LAT,LON
75        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF

      DTLX=R*(ACOS(SIN(TLXLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (TLXLAT*(PI/180))*COS(LAT*(PI/180))*COS((TLXLON-LON)*(PI/180))))
      IF(DTLX .LT. RNG) THEN
        WRITE(80,85)YR,MO,DAY,HR,MIN,SEC,LAT,LON
85        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF

      DVNX=R*(ACOS(SIN(VNXLAT*(PI/180))*SIN(LAT*(PI/180))+COS
     $   (VNXLAT*(PI/180))*COS(LAT*(PI/180))*COS((VNXLON-LON)*(PI/180))))
      IF(DVNX .LT. RNG) THEN
        WRITE(90,95)YR,MO,DAY,HR,MIN,SEC,LAT,LON
95        FORMAT(I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,I2,1X,F6.3,1X,F8.3)
      ENDIF
      GO TO 1
999   STOP
  end
```

APPENDIX D

This appendix contains the Fortran that combines the WATADS Algorithm output files into one file. The code in this program is not ANSI-standard Fortran.

```
C23456789012345678901234567890123456789012345678901234567890123456789012
C THIS PROGRAM TAKES INFORMATION FROM THE FORT.13, FORT.14, AND 3D.DAT
C FILES FROM WATADS ALGORITHM OUTPUT, AND COMBINES THE DATA INTO ONE
C FILE.

      PROGRAM MIXFILES
      IMPLICIT NONE

C VARIABLES:

      INTEGER INITHR,INITMIN,INITSEC,NOSTRMS
      INTEGER COMON,CODAY,COYR,COHR,COMIN,COSEC
      INTEGER HTHR,HTMIN,HTSTMS
      INTEGER I,J,GOTIT,CID14(100),CID13(100)
      REAL AZ(100),RNG(100),LAT(100),LON(100),DIR(100),SPD(100)
      REAL RDALAT,RDALON
      REAL MASS(100),VOL(100),AREA(100)
      REAL TMPAZ,TMPRNG,TMPDIR,TMPSPD,TMPMASS,TMPVOL,TMPAREA
      REAL MAZ,MRAN,CBOT,CTOP,MREF,HMAXZ
      REAL STBOT(100),STTOP(100),STMXZ(100),HTMXZ(100)
      CHARACTER X,DUM,BLANK
      PARAMETER (BLANK = ' ')

C INITIALIZE THE VALUES

      DATA    (LON(I),I=1,100) / 100 * 0.0 /
      DATA    (LAT(I),I=1,100) / 100 * 0.0 /
      DATA     (AZ(I),I=1,100) / 100 * 0.0 /
      DATA    (RNG(I),I=1,100) / 100 * 0.0 /
      DATA   (MASS(I),I=1,100) / 100 * 0.0 /
      DATA    (VOL(I),I=1,100) / 100 * 0.0 /
      DATA   (AREA(I),I=1,100) / 100 * 0.0 /
      DATA  (STBOT(I),I=1,100) / 100 * 0.0 /
      DATA  (STTOP(I),I=1,100) / 100 * 0.0 /
      DATA  (STMXZ(I),I=1,100) / 100 * 0.0 /
      DATA  (HTMXZ(I),I=1,100) / 100 * 0.0 /

      OPEN (UNIT=9,  FILE='FORT.14', STATUS='UNKNOWN')
      OPEN (UNIT=10, FILE='FORT.13', STATUS='UNKNOWN')
      OPEN (UNIT=11, FILE='3D.DAT',  STATUS='UNKNOWN')
      OPEN (UNIT=12, FILE='STORM',   STATUS='UNKNOWN')

C THE LATITUDE AND LONGITUDE OF THE RDA

      RDALAT =  34.362
      RDALON = -98.977
```

```
C FIRST READ IN DATA FROM THE FORT.14 FILE

1     READ (9,115,END=999) X
115     FORMAT(1X,A1)
      PRINT*,X

      IF (X .EQ. 'N' .OR. X .EQ. 'C') THEN
        READ (9,10,END=999) INITHR,INITMIN,INITSEC,NOSTRMS
10      FORMAT(////,5X,3I2,47X,I3)
      ELSEIF (X .EQ. ' ') THEN
        READ (9,436,END=999) INITHR,INITMIN,INITSEC,NOSTRMS
436     FORMAT(///,5X,3I2,47X,I3)
      ELSE
        READ (9,434,END=999) INITHR,INITMIN,INITSEC,NOSTRMS
434     FORMAT (/////,5X,3I2,47X,I3)
      ENDIF
      PRINT*,NOSTRMS

C READ IN THE NUMBER OF STORMS; IF NOSTRMS EQUALS ZERO, THEN SKIP THE
C FORT.13 DATA

      IF (NOSTRMS .EQ. 0) THEN
        READ (9,534,END=999) DUM
534     FORMAT (A44)
        GO TO 899
      ENDIF

C IF THE NUMBER OF STORMS IS NOT ZERO, READ IN THE NUMBER OF LINES
C CORRESPONDING TO THE NUMBER OF STORMS
C THE STORMID IS IN NUMERICAL ORDER IN THIS VOLUME SCAN

      READ (9,20) !SKIP THE HEADER LINE IN THE FILE
20      FORMAT(1X)

C READ IN THE VOLUME SCAN FROM THE FORT.14 FILE

      DO I=1,NOSTRMS
        READ (9,30,END=999)CID14(I),TMPAZ,TMPRNG,TMPDIR,TMPSPD
30      FORMAT (I3,4F8.1)

C CID14 IS USED TO IDENDIFY EACH STORM AND ASSIGN TO IT THE CELL ID
C NUMBER THAT IS WAS GIVEN IN THE FIRST VOLUME SCAN

        AZ(CID14(I))=TMPAZ
        RNG(CID14(I))=TMPRNG
        DIR(CID14(I))=TMPDIR
        SPD(CID14(I))=TMPSPD
      ENDDO

C DISCARD THE HEADER LINES, BUT READ IN THE MONTH, DAY, YEAR, HOUR,
C MINUTE, AND SECOND FROM THE FORT.13 FILE

      READ (10,50)COMON,CODAY,COYR,COHR,COMIN,COSEC
50      FORMAT(///////////,13X,3I2,13X,3I2)
      PRINT*,'***',CODAY,COYR,COHR,COMIN,COSEC
      GO TO 787

899   READ (10,51) DUM
```

```
51       FORMAT (A44,///////////)
      GO TO 901

C READ IN THE DATA FROM THE FORT.13 FILE.  THE NUMBER OF LINE IS EQUAL
C TO THE NUMBER OF STORMS (NOSTRMS) FROM THE FORT.14 FILE

787   READ(10,20) !SKIP THE HEADER LINE IN THE FILE

C THIS LOOP READS IN THE MASS, VOLUME, AND AREA FROM THE FORT.13 FILE

      DO I=1,NOSTRMS
        READ(10,60)CID13(I),TMPMASS,TMPVOL,TMPAREA
60        FORMAT(I3,49X,2F8.0,16X,F8.1)

C CID14 IS USED TO SORT THE DATA IN THE CORRECT RECORD BECAUSE
C CID13 AND CID14 ARE NOT IN NUMERICAL AGREEMENT

        MASS(CID14(I))=TMPMASS
        VOL(CID14(I)) =TMPVOL
        AREA(CID14(I))=TMPAREA
      ENDDO

C READ AND DISCARD THE HEADER LINES FROM 3D.DAT, BUT READ THE
C HOUR, MINUTE, AND NUMBER OF STORMS
C FIRST CHECK AND SEE IF THERE IS A TIME GAP BETWEEN VOLUME SCANS
C IF SO, SKIP ONE MORE BLANK LINE BEFORE READING IN THE DATA

901   READ (11,63) X
63      FORMAT (1X,A1)
      IF (X .EQ. 'N' .OR. X .EQ. 'C') THEN
        READ (11,444) HTHR,HTMIN,HTSTMS
444       FORMAT(////,5X,2I2,49X,I2,//)
      ELSEIF (X .EQ. ' ') THEN
        READ (11,445,END=999) HTHR,HTMIN,HTSTMS
445       FORMAT(///,5X,2I2,49X,I2,//)
      ELSE
        READ (11,437,END=999) HTHR,HTMIN,HTSTMS
437       FORMAT (/////,5X,2I2,49X,I2,//)
      ENDIF

C IF NOSTRMS EQUALS ZERO, THEN SKIP TO THE NEXT TIME

      IF (HTSTMS .EQ. 0) THEN
        READ (9,544,END=999) DUM
544       FORMAT (A44)
        GO TO 1
      ENDIF
      PRINT*,HTMIN,COMIN

C CHECK THE TIME TO ENSURE THAT THE VOLUME SCANS MATCH

      IF (HTHR .NE. COHR .OR. HTMIN .NE. COMIN) THEN
        PRINT *,'DATA BETWEEN THE FILES DOES NOT MATCH',HTHR
      ENDIF

C THIS LOOP READS IN THE DATA FROM 3D.DAT

      DO J=1,HTSTMS
```

```
C VARIABLE GOTIT = 0 UNTIL A MATCH IS FOUND

        GOTIT = 0
        READ(11,64) MAZ,MRAN,CBOT,CTOP,MREF,HMAXZ
64        FORMAT(4X,F4.0,1X,F4.0,2X,2F5.1,18X,F2.0,5X,F5.1)

C THIS LOOP FINDS THE MATCHING STORM WITHIN THE CURRENT VOLUME SCAN

        DO I=1,100

C IF GOTIT IS STILL ZERO, THEN MUST CONTINUE TO LOOK FOR STORM MATCH

          IF (GOTIT .EQ. 0) THEN

C THRESHOLD: AZIMUTH MUST BE WITHIN 1/2 DEGREE AND RANGE WITHIN 1 NM

            IF(ABS((AZ(I)-MAZ)) .LE. 0.5
     $         .AND.(ABS(RNG(I)*0.539-MRAN)) .LE. 1.0) THEN

C HAVING MATCHED THE STORMS, PLACE INFORMATION IN CORRECT BIN

              STBOT(I) = CBOT
              STTOP(I) = CTOP
              STMXZ(I) = MREF
              HTMXZ(I) = HMAXZ

C SET GOTIT TO ONE SO LOOP FINISHES MORE EFFICIENTLY

              GOTIT = 1
            ELSE
            ENDIF
          ENDIF
        ENDDO
      ENDDO

C ALL THE DATA FROM THE FIRST TIME PERIOD HAS BEEN READ
C IN CORRECTLY, A FEW ADJUSTMENTS ARE MADE BEFORE THE DATA IS
C WRITTEN TO A FILE
C FIRST CONVERT AZ/RNG TO LAT/LON BASED ON LAT/LON OF RDA

      CALL LATLON (AZ,RNG,LAT,LON,RDALAT,RDALON)

C THEN ROUND OFF TO THE NEAREST MINUTE

      CALL RNDOFF (COHR,COMIN,COSEC)

C AND ZERO OUT THE LATS AND LONS WITHOUT DATA

      DO I=1,100
        IF (AZ(I) .EQ. 0 .AND. RNG(I) .EQ. 0 .AND. DIR(I) .EQ. 0
     $     .AND. SPD(I) .EQ. 0 .AND. MASS(I) .EQ. 0 .AND. VOL(I)
     $     .EQ. 0 .AND. AREA(I) .EQ. 0 .AND. STBOT(I) .EQ. 0 .AND.
     $     STTOP(I) .EQ. 0 .AND. STMXZ(I) .EQ. 0 .AND. HTMXZ(I) .EQ.
     $     0) THEN
          LAT(I)= 0.0
          LON(I)= 0.0
        ENDIF
```

```
        ENDDO

C WRITE THE ARRAY TO FILE
C THE OUTPUT FILE WILL CONTAIN:
C   CID, YEAR, MONTH, DAY, HOUR, MINUTE, LATITUDE, LONGITUDE,
C   AZIMUTH, RANGE, DIRECTION, SPEED, MASS, VOLUME, AREA,
C   STORM BOTTOM AND TOP, MAX Z, AND HEIGHT OF MAX Z.

      DO I=1,100
        WRITE(12,90)I,COYR,COMON,CODAY,COHR,COMIN,LAT(I),LON(I),
     $      AZ(I),RNG(I),DIR(I),SPD(I),MASS(I),VOL(I),AREA(I),
     $      STBOT(I),STTOP(I),STMXZ(I),HTMXZ(I)
90        FORMAT(I3,1X,5I2,F7.3,F9.3,4F6.1,2F6.0,F5.1,2F5.1,F4.0,F5.1)
      ENDDO

C NOW ZERO OUT THE VALUES BEFORE THE NEXT VOLUME SCAN IS READ

      CALL ZERO (AZ,RNG,DIR,SPD,MASS,VOL,AREA,STBOT,STTOP,STMXZ,HTMXZ)

C BEGIN THE SEQUENCE AGAIN FOR SUCCESSIVE VOLUME SCANS

      GO TO 1
999   STOP
      END

      SUBROUTINE LATLON (AZ,RNG,LAT,LON,RDALAT,RDALON)

C THIS SUBROUTINE CONVERTS AZIMUTH/RANGE TO LATITUDE/LONGITUDE BASED ON
C THE LATITUDE AND LONGITUDE OF THE RDA
C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.

      REAL AZ(100),RNG(100),LAT(100),LON(100)
      REAL RDALAT,RDALON,POLERAD,ERAD,DIFF
      DOUBLE PRECISION DEG2RAD,KM2DEG,RAD2DEG
      REAL ADEG(100),BDEG(100),ADAA(100)
      DOUBLE PRECISION A(100),B(100),C(100),BB(100)
      INTEGER I

C MUST CONVERT NEXRAD ANGLE TO SCIENTIFIC ANGLE
C PI/180 = 0.01745
C MUST CONVERT KM TO DEGREES OF LATITUDE
C 111.195 KM = 1° LATITUDE
C POLERAD IS THE RADIUS OR THE EARTH AT THE NORTH POLE
C DIFF IS THE DIFFERENCE OF THE RADIUS OF THE EARTH BETWEEN THE EQUATOR
C AND THE POLE

      RAD2DEG = 57.296
      DEG2RAD = 0.0174532925
      KM2DEG  = 111.120
      POLERAD = 6356.912
      DIFF    = 21.476

C USING THE SPHERICAL RIGHT TRIANGLE:  A, B, C BEING THE ANGLES OF
C THE RIGHT TRIANGLE; AA AND BB ARE THE SIDES OF THE RIGHT TRIANGLE
C ERAD IS THE RADIUS OF THE EARTH AT THE LATITUDE OF THE RDA
```

```
      DO I=1,100
        ADAA(I)=AZ(I)
        ERAD = POLERAD + ( DIFF*( COS(2.0*RDALAT*DEG2RAD)+1)/2.0)
        C(I) = RNG(I) / ERAD
        B(I) = ASIN ( SIN(ADAA(I)*DEG2RAD) * SIN(C(I)) )
        BB(I) =  ASIN ( COS(ADAA(I)*DEG2RAD) * COS(B(I)) )
        A(I) = ASIN ( SIN(BB(I)) * SIN(C(I)) )
        ADEG(I) = A(I) * RAD2DEG
        BDEG(I) = B(I) * RAD2DEG
        LAT(I) = RDALAT + ADEG(I)
        LON(I) = RDALON + BDEG(I)
      ENDDO
      END

C THIS SUBROUTINE ROUNDS TIME TO THE NEAREST MINUTE

      INTEGER HR,MIN,SEC

      IF (SEC.GE.30.AND.MIN.EQ.59) THEN
        MIN = MIN + 1
        HR  = HR  + 1
      ELSE
        IF (SEC.GE.30.AND.MIN.LT.59) THEN
          MIN = MIN + 1
        ENDIF
      ENDIF
      END

      SUBROUTINE ZERO (AZ,RNG,DIR,SPD,MASS,VOL,AREA,
     $                 STBOT,STTOP,STMXZ,HTMXZ)

C THIS SUBROUTINE ZEROES THE DATA FROM CURRENT ARRAY

      INTEGER I
      REAL AZ(100),RNG(100),DIR(100),SPD(100),LAT(100),LON(100)
      REAL MASS(100),VOL(100),AREA(100)
      REAL STBOT(100),STTOP(100),STMXZ(100),HTMXZ(100)

      DO I=1,100
        LON(I)   =0.0
        LAT(I)   =0.0
        AZ(I)    =0.0
        RNG(I)   =0.0
        DIR(I)   =0.0
        SPD(I)   =0.0
        MASS(I)  =0.0
        VOL(I)   =0.0
        AREA(I)  =0.0
        STBOT(I)=0.0
        STTOP(I)=0.0
        STMXZ(I)=0.0
        HTMXZ(I)=0.0
      ENDDO
      END
```

APPENDIX E

This appendix contains the Fortran program that combines the WATADS and lightning data, and then computes distances between lightning strikes and closest storm centroids. The code in this program is not ANSI-standard Fortran.

```
C23456789012345678901234567890123456789012345678901234567890123456789012
C THIS PROGRAM IMPORTS LIGHTNING STRIKE DATA AND THE COMBINED WATADS
C DATA, THEN COMPUTES THE DISTANCE FROM THE LIGHTNING STRIKE TO THE
C NEAREST STORM CENTROID.  THE PROGRAM THEN CALCULATES THE AZIMUTH ANGLE
C OF STORM MOTION TO THE LIGHTNING STRIKE, AND THE DISTANCE FROM THE
C EDGE OF THE STORM CELL TO THE LIGHTNING STRIKE.

      PROGRAM LIGHTNING
      IMPLICIT NONE

C VARIABLES:

      INTEGER CSMON,CSDAY,CSHR,CSMIN,DIFFMIN,VSDIFF
      INTEGER OSMON,OSDAY,OSHR,OSMIN,CVSMIN,LIMIN,OVSMIN
      INTEGER LMON,LDAY,LHR,LMIN,LSEC
      INTEGER I,DUM
      REAL OSLAT(100),OSLON(100),LATBET(100),LONBET(100)
      REAL CSLAT(100),CSLON(100),LATDIFF(100),LONDIFF(100)
      REAL LILAT,LILON,LIAZ,LIRNG,RDALAT,RDALON
      REAL OSAZ(100),OSRNG(100),OBOT(100),OTOP(100),OMXZ(100)
      REAL OHMXZ(100),IOSLAT(100),IOSLON(100)
      REAL OSDIR(100),OSSPD(100),OMASS(100),OVOL(100),OAREA(100)
      REAL CSDIR(100),CSSPD(100),CMASS(100),CVOL(100),CAREA(100)
      REAL CSAZ(100),CSRNG(100),CBOT(100),CTOP(100),CMXZ(100)
      REAL CHMXZ(100),ADEG(100),BDEG(100),TDIR(100),TRNG(100)
      REAL POLERAD,DIFF,ERAD(100)
      DOUBLE PRECISION A(100),B(100),C(100),BB(100)
      DOUBLE PRECISION DEG2RAD,KM2DEG,RAD2DEG

C INITIALIZE THE VALUES

      DATA     (OSLAT(I),I=1,100) / 100 * 0.0 /
      DATA     (OSLON(I),I=1,100) / 100 * 0.0 /
      DATA    (LATBET(I),I=1,100) / 100 * 0.0 /
      DATA    (LONBET(I),I=1,100) / 100 * 0.0 /
      DATA     (CSLAT(I),I=1,100) / 100 * 0.0 /
      DATA     (CSLON(I),I=1,100) / 100 * 0.0 /
      DATA   (LATDIFF(I),I=1,100) / 100 * 0.0 /
      DATA   (LONDIFF(I),I=1,100) / 100 * 0.0 /
      DATA      (OSAZ(I),I=1,100) / 100 * 0.0 /
      DATA     (OSRNG(I),I=1,100) / 100 * 0.0 /
      DATA      (OBOT(I),I=1,100) / 100 * 0.0 /
      DATA      (OTOP(I),I=1,100) / 100 * 0.0 /
      DATA      (OMXZ(I),I=1,100) / 100 * 0.0 /
      DATA     (OHMXZ(I),I=1,100) / 100 * 0.0 /
```

```
      DATA     (OSDIR(I),I=1,100) / 100 * 0.0 /
      DATA     (OSSPD(I),I=1,100) / 100 * 0.0 /
      DATA     (OMASS(I),I=1,100) / 100 * 0.0 /
      DATA      (OVOL(I),I=1,100) / 100 * 0.0 /
      DATA     (OAREA(I),I=1,100) / 100 * 0.0 /
      DATA     (CSDIR(I),I=1,100) / 100 * 0.0 /
      DATA     (CSSPD(I),I=1,100) / 100 * 0.0 /
      DATA     (CMASS(I),I=1,100) / 100 * 0.0 /
      DATA      (CVOL(I),I=1,100) / 100 * 0.0 /
      DATA     (CAREA(I),I=1,100) / 100 * 0.0 /
      DATA      (CSAZ(I),I=1,100) / 100 * 0.0 /
      DATA     (CSRNG(I),I=1,100) / 100 * 0.0 /
      DATA      (CBOT(I),I=1,100) / 100 * 0.0 /
      DATA      (CTOP(I),I=1,100) / 100 * 0.0 /
      DATA      (CMXZ(I),I=1,100) / 100 * 0.0 /
      DATA     (CHMXZ(I),I=1,100) / 100 * 0.0 /

C OPEN THE FILES

      OPEN (UNIT=9, FILE='STORMB', STATUS='UNKNOWN')
      OPEN (UNIT=10, FILE='FDRAPR', STATUS='UNKNOWN')
      OPEN (UNIT=11, FILE='1FDRA', STATUS='UNKNOWN')
      OPEN (UNIT=12, FILE='2FDRA', STATUS='UNKNOWN')

C INITIAL VALUES
C POLERAD IS THE RADIUS OR THE EARTH AT THE NORTH POLE
C DIFF IS THE DIFFERENCE OF THE RADIUS OF THE EARTH BETWEEN THE EQUATOR
C AND THE POLE

      DUM=0
      RDALAT  =  34.362
      RDALON  = -98.977
      RAD2DEG = 57.296
      DEG2RAD = 0.0174532925
      KM2DEG  = 111.120
      POLERAD = 6356.912
      DIFF    = 21.476

C READ IN THE DATA FROM THE STORM FILE, EACH VOLUME SCAN IS 100 LINES
C LONG.  THE VOLUME SCAN READ IN MOST RECENTLY IS CALLED THE "CURRENT"
C VOLUME SCAN, DENOTED BY THE "C" IN FRONT OF EACH VARIABLE

5     DO I=1,100
        READ (9,20,END=999) CSMON,CSDAY,CSHR,CSMIN,CSLAT(I),CSLON(I),
     $        CSAZ(I),CSRNG(I),CSDIR(I),CSSPD(I),CMASS(I),
     $        CVOL(I),CAREA(I),CBOT(I),CTOP(I),CMXZ(I),CHMXZ(I)
20          FORMAT (6X,4I2,F7.3,F9.3,4F6.1,2F6.0,3F5.1,F4.0,F5.1)
      ENDDO

C CONVERT VOLUME SCAN TO MINUTES.  THIS IS DONE SO THE TIME BETWEEN THE
C LIGHTNING DATA AND THE VOLUME SCAN CAN BE COMPARED

      CVSMIN=(CSDAY*24*60)+(CSHR*60)+CSMIN
      IF (DUM .EQ. 1) THEN
        GO TO 444
      ENDIF

C READ IN THE LIGHTNING DATA
```

```
100    READ (10,40,END=999) LMON,LDAY,LHR,LMIN,LSEC,LILAT,LILON
40       FORMAT (4X,I1,4I3,F7.3,F9.3)

C NOW CONVERT LIGHTNING LATITUDE AND LONGITUDE TO AZIMUTH
C AND RANGE FROM THE RDA

       CALL LILATLON (LIAZ,LIRNG,LILAT,LILON,RDALAT,RDALON)

C ROUND OFF THE LIGHTNING DATA TO THE NEAREST MINUTE

       CALL RNDOFF (LDAY,LHR,LMIN,LSEC)

C CONVERT LIGHTNING DATA TO MINUTES

       LIMIN=(LDAY*24*60)+(LHR*60)+LMIN

*USE ARITHMETIC IF STATEMENT TO SEE IF LIMIN-VSMIN IS LESS THAN ZERO,
*EQUAL TO ZERO, OR GREATER THAN ZERO

444    IF (LIMIN-CVSMIN) 100,110,120

C THE TIMES ARE EQUAL, SO PROCESS THE SHORTEST DISTANCES

110    CALL PROCESS (LILAT,LILON,LIAZ,LIRNG,
     $      CSLAT,CSLON,CSAZ,CSRNG,LDAY,LMON,LHR,
     $      LMIN,LSEC,CSDIR,CSSPD,CMASS,CVOL,CAREA,CBOT,CTOP,CMXZ,CHMXZ)

C NOW THAT DISTANCES HAVE BEEN PROCESSED, PUT THE CURRENT VOLUME SCAN
C INTO AN "OLD" VOLUME SCAN ARRAY, DENOTED BY "O"

       DO I=1,100
         OSMON=CSMON
         OVSMIN=CVSMIN
         OSDAY=CSDAY
         OSHR=CSHR
         OSMIN=CSMIN
         OSLAT(I)=CSLAT(I)
         OSLON(I)=CSLON(I)
         OSAZ(I)=CSAZ(I)
         OSRNG(I)=CSRNG(I)
         OSDIR(I)=CSDIR(I)
         OSSPD(I)=CSSPD(I)
         OMASS(I)=CMASS(I)
         OVOL(I)=CVOL(I)
         OAREA(I)=CAREA(I)
         OBOT(I)=CBOT(I)
         OTOP(I)=CTOP(I)
         OMXZ(I)=CMXZ(I)
         OHMXZ(I)=CHMXZ(I)
       ENDDO

C SINCE A DISTANCE HAS BEEN PROCESSED IT IS TIME TO READ IN ANOTHER
C LIGHTNING STRIKE

       GO TO 100

120    DO I=1,100
```

```
C NEED TO READ IN ANOTHER VOLUME SCAN TO COMPARE TO THIS LIGHTNING
C STRIKE, BUT FIRST PUT THE CURRENT VOLUME SCAN INTO THE OLD VOLUME SCAN

          OVSMIN=CVSMIN
          OSDAY=CSDAY
          OSHR=CSHR
          OSMIN=CSMIN
          OSLAT(I)=CSLAT(I)
          OSLON(I)=CSLON(I)
          OSAZ(I)=CSAZ(I)
          OSRNG(I)=CSRNG(I)
          OSDIR(I)=CSDIR(I)
          OSSPD(I)=CSSPD(I)
          OMASS(I)=CMASS(I)
          OVOL(I)=CVOL(I)
          OAREA(I)=CAREA(I)
          OBOT(I)=CBOT(I)
          OTOP(I)=CTOP(I)
          OMXZ(I)=CMXZ(I)
          OHMXZ(I)=CHMXZ(I)
        ENDDO

C NOW READ IN A NEW VOLUME SCAN

        DO I=1,100
          READ (9,30,END=999) CSMON,CSDAY,CSHR,CSMIN,CSLAT(I),CSLON(I),
     $        CSAZ(I),CSRNG(I),CSDIR(I),CSSPD(I),CMASS(I),
     $        CVOL(I),CAREA(I),CBOT(I),CTOP(I),CMXZ(I),CHMXZ(I)
30          FORMAT (6X,4I2,F7.3,F9.3,4F6.1,2F6.0,3F5.1,F4.0,F5.1)
        ENDDO

C COMPUTE NUMBER OF MINUTES OF NEW VOLUME SCAN

        CVSMIN=(CSDAY*24*60)+(CSHR*60)+CSMIN

C CHECK IF THE STRIKE IS BETWEEN VOLUME SCANS, IF NOT, READ IN ANOTHER
C LIGHTNING STRIKE

        IF (LIMIN .GT. CVSMIN .AND. LIMIN .LT. OVSMIN) THEN
          GO TO 100
        ENDIF

C THE STRIKE IS BETWEEN VOLUME SCANS, NOW INTERPOLATE THE STORM CELL
C FIRST COMPUTE THE NUMBER OF MINUTES BETWEEN VOLUME SCANS THE LIGHTNING
C STRIKE IS IN

777     DIFFMIN=LIMIN-OVSMIN
        VSDIFF=CVSMIN-OVSMIN

C CHECK IF DIFFMIN IS GREATER THAN OR EQUAL TO FIVE OR SIX, IF SO, A NEW
C LIGHTNING STRIKE MUST BE READ IN

        IF (VSDIFF .EQ. 5 .AND. DIFFMIN .GE. 5 .OR. VSDIFF .EQ. 6
     $     .AND. DIFFMIN .GE. 6) THEN
          GO TO 120
        ENDIF
```

```
C IF THE DIFFERENCE BETWEEN VOLUME SCANS IS GREATER THAN 6 MINUTES, A
C NEW VOLUME SCAN MUST BE READ IN

      IF (VSDIFF .GT. 6) THEN
        GO TO 100
      ENDIF

      DO I=1,100

C CHECK TO SEE IF THE CELL DISAPPEARS, IF SO, USE THE SPEED AND
C DIRECTION OF THE CENTROID TO INTERPOLATE, MUST MEET 4 CRITERIA

        IF (CSLAT(I) .EQ. 0.0 .AND. CSLON(I) .EQ. 0.0) THEN

C PASSES STEP 1

          GO TO 610
        ELSE
          GO TO 554
        ENDIF

610     IF (OSLAT(I) .NE. 0.0 .AND. OSLON(I) .NE. 0.0) THEN

C PASSES STEP 2

          GO TO 611
        ELSE
          GO TO 554
        ENDIF

611     IF (OSDIR(I) .EQ. 0.0 .OR. OSDIR(I) .EQ. 999.0) THEN
          GO TO 554
        ELSE

C PASSES STEP 3

          GO TO 612
        ENDIF

612     IF (OSSPD(I) .EQ. 0.0 .OR. OSSPD(I) .EQ. 999.0) THEN
          GO TO 554
        ELSE

C PASSES STEP 4

          GO TO 553
        ENDIF

C NOW INTERPOLATE USING THE SPEED AND DIRECTION OF THE CENTROID

553     IF (OSDIR(I) .GT. 180.0) THEN
          TDIR(I) = OSDIR(I) - 180.0
        ELSE
          TDIR(I) = OSDIR(I)
        ENDIF
          PRINT*,'******************************DISAPPEARING STORM'

C NOW COMPUTE THE NEW LATITUDE AND LONGITUDE OF THE CENTROID USING
```

```
C SPHERICAL COORDINATES
C FIRST COMPUTE THE NEW RANGE OF THE CENTROID

        TRNG(I) = ((OSSPD(I)*60.0)/1000.0)*DIFFMIN

C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.
C USING THE SPHERICAL RIGHT TRIANGLE:  A, B, C BEING THE ANGLES OF
C THE RIGHT TRIANGLE; AA AND BB ARE THE SIDES OF THE RIGHT TRIANGLE
C ERAD IS THE RADIUS OF THE EARTH AT THE LATITUDE OF THE RDA

        ERAD(I) = POLERAD +( DIFF*( COS(2.0*OSLAT(I)*DEG2RAD)+1)/2.0)
        C(I) = TRNG(I) / ERAD(I)
        B(I) = ASIN ( SIN(TDIR(I)*DEG2RAD) * SIN(C(I)) )
        BB(I) =  ASIN ( COS(TDIR(I)*DEG2RAD) * COS(B(I)) )
        A(I) = ASIN ( SIN(BB(I)) * SIN(C(I)) )
        ADEG(I) = A(I) * RAD2DEG
        BDEG(I) = B(I) * RAD2DEG
        IOSLAT(I) = OSLAT(I) + ADEG(I)
        IOSLON(I) = OSLON(I) + BDEG(I)
        PRINT*,I,TDIR(I),TRNG(I),IOSLAT(I),IOSLON(I)
        GO TO 555

C IF NO LATITUTE AND LONGITUDE DATA IS AVALIABLE, THEN THE COMPUTED
C LATITUDE AND LONGITUDE MUST BE ZERO

554     IF (CSLAT(I) .EQ. 0.0 .OR. OSLAT(I) .EQ. 0.0) THEN
          IOSLAT(I)=0.0
          IOSLON(I)=0.0
          GO TO 555
        ENDIF

C INTERPOLATE USING THE OLD AND NEW VOLUME SCANS, ASSUMING A STRAIGHT
C MOVING STORM

        LATDIFF(I)=ABS(CSLAT(I)-OSLAT(I))
        LONDIFF(I)=ABS(CSLON(I)-OSLON(I))

        IF (OSLAT(I) .LT. CSLAT(I)) THEN
          LATBET(I)=OSLAT(I)+((LATDIFF(I)/VSDIFF)*DIFFMIN)
        ELSE
          LATBET(I)=OSLAT(I)-((LATDIFF(I)/VSDIFF)*DIFFMIN)
        ENDIF

        IF (OSLON(I) .LT. CSLON(I)) THEN
          LONBET(I)=CSLON(I)+((LONDIFF(I)/VSDIFF)*DIFFMIN)
        ELSE
          LONBET(I)=OSLON(I)-((LONDIFF(I)/VSDIFF)*DIFFMIN)
        ENDIF

        IOSLAT(I)=LATBET(I)
        IOSLON(I)=LONBET(I)
555     CONTINUE
      ENDDO

C NOW AFTER INTERPOLATION, NEW AZIMUTH AND RANGE FROM THE RDA TO THE
```

```
C CENTROID MUST BE CALCULATED

      CALL CLATLON (OSAZ,OSRNG,IOSLAT,IOSLON,RDALAT,RDALON)

*NOW WE HAVE INTERPOLATED, TIME TO COMPUTE DISTANCE

      CALL INTERP (LILAT,LILON,LIAZ,LIRNG,
     $     IOSLAT,IOSLON,OSAZ,OSRNG,LDAY,
     $     LMON,LHR,LMIN,LSEC,OSDIR,OSSPD,OMASS,OVOL,OAREA,
     $     OBOT,OTOP,OMXZ,OHMXZ)

C NOW READ IN THE NEXT LIGHTNING STRIKE AND SEE IF IT'S BETWEEN THESE
C VOLUME SCANS

      READ (10,44,END=999) LMON,LDAY,LHR,LMIN,LSEC,LILAT,LILON
44      FORMAT (4X,I1,4I3,F7.3,F9.3)

C NOW CONVERT LIGHTNING LATITUDE AND LONGITUDE TO AZIMUTH
C AND RANGE FROM THE RDA

      CALL LILATLON (LIAZ,LIRNG,LILAT,LILON,RDALAT,RDALON)

C NOW ROUNDOFF TO THE NEAREST MINUTE

      CALL RNDOFF (LDAY,LHR,LMIN,LSEC)

C CONVERT LIGHTNING DATA TO MINUTES

      LIMIN=(LDAY*24*60)+(LHR*60)+LMIN
      PRINT*,LMON,LDAY,LHR,LMIN

C CHECK IF THE STRIKE IS BETWEEN VOLUME SCANS, OR IF THE TIMES MATCH

      IF (LIMIN .EQ. CVSMIN) THEN
        GO TO 110
      ENDIF

      IF (LIMIN .GT. CVSMIN) THEN
        GO TO 120
      ENDIF

      IF (LIMIN .GT. CVSMIN .AND. LIMIN .LT. OVSMIN) THEN
        GO TO 888
      ENDIF

C NOW IT IS BETWEEN VOLUME SCANS -- COMPUTE DISTANCE

      GO TO 777

C PUT THE CURRENT VOLUME SCAN ARRAY INTO THE OLD VOLUME SCAN ARRAY, AND
C THEN READ IN A NEW VOLUME SCAN

888   DO I=1,100
        OVSMIN=CSMIN
        OSDAY=CSDAY
        OSHR=CSHR
        OSMIN=CSMIN
        OSLAT(I)=CSLAT(I)
```

```
          OSLON(I)=CSLON(I)
          OSAZ(I)=CSAZ(I)
          OSRNG(I)=CSRNG(I)
          OSDIR(I)=CSDIR(I)
          OSSPD(I)=CSSPD(I)
          OMASS(I)=CMASS(I)
          OVOL(I)=CVOL(I)
          OAREA(I)=CAREA(I)
          OBOT(I)=CBOT(I)
          OTOP(I)=CTOP(I)
          OMXZ(I)=CMXZ(I)
          OHMXZ(I)=CHMXZ(I)
        ENDDO
        DUM=1
        GO TO 5
999     CONTINUE
        END

        SUBROUTINE RNDOFF(DAY,HR,MIN,SEC)

C THIS SUBROUTINE ROUNDS TIME TO THE NEAREST MINUTE

        INTEGER DAY,HR,MIN,SEC

        IF (SEC .GE. 30 .AND. MIN .EQ. 59 .AND. HR .EQ. 23) THEN
          DAY = DAY + 1
          HR = 0
          MIN = 0
        ELSE
          IF (SEC .GE. 30 .AND. MIN .EQ. 59 .AND. HR .LT. 23) THEN
            MIN = 0
            HR  = HR  + 1
            ELSE
              IF (SEC .GE. 30 .AND. MIN .LT. 59 .AND. HR .LT. 23) THEN
                MIN = MIN + 1
              ENDIF
          ENDIF
        ENDIF
        END

        SUBROUTINE PROCESS (LILAT,LILON,LIAZ,LIRNG,
     $      CSLAT,CSLON,CSAZ,CSRNG,LDAY,LMON,LHR,
     $      LMIN,LSEC,CSDIR,CSSPD,CMASS,CVOL,CAREA,CBOT,CTOP,CMXZ,CHMXZ)

C THIS SUBROUTINE CALCULATES THE DISTANCE FROM THE LIGHTNING STRIKE TO
C THE CENTROID FOR EACH CENTROID, THEN KEEPS C THE CLOSEST 2 DISTANCES.
C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.
C THIS SUBROUTINE IS GOOD FOR NONINTPEROLATED CENTROIDS ONLY
C VARIABLES:

        REAL LILAT,LILON,CSLAT(100),CSLON(100)
        REAL DIST,CSAZ(100),CSRNG(100),CBOT(100),CTOP(100),CMXZ(100)
        REAL CHMXZ(100),SQRT,LIAZ,LIRNG
        REAL CSDIR(100),CSSPD(100),CMASS(100),CVOL(100)
        REAL CAREA(100),LDIST,IBDIST,IADIST
```

```
      REAL IACSDIR,IBCSDIR,IACSSPD,IBCSSPD,IACMASS,IBCMASS
      REAL IACVOL,IBCVOL,PI,IACSLAT,IBCSLAT,IACSLON,IBCSLON
      REAL IACSAZ,IBCSAZ,IACSRNG,IBCSRNG
      REAL IACTOP,IBCTOP,IACBOT,IBCBOT,IACMXZ,IBCMXZ,IACHMXZ
      REAL IBCHMXZ,IACAREA,IBCAREA,IBCSRAD,IBAREADIST,IACSRAD
      REAL IAAREADIST
      REAL ERAD,POLERAD,DIFF
      DOUBLE PRECISION A,B,C,DEG2RAD
      INTEGER LMON,LDAY,LHR,LMIN,IALMON,IBLMON,IALDAY,IBLDAY
      INTEGER IALHR,IBLHR,IALMIN,IBLMIN,LSEC,IALSEC,IBLSEC
      PARAMETER(R=6378.0)
      POLERAD = 6356.912
      DIFF = 21.476
      DEG2RAD = 0.0174532925
      PI=ATAN(1.0)*4.0
      LDIST=1000.0

C SET INITIAL DISTANCE THRESHOLDS AT 50.0 AND 70.0 NM

      IADIST=50.0
      IBDIST=70.0

      DO I=1,100

C FIRST ZERO OUT ALL LATITUDES AND LONGITUDES WITHOUT DATA

        IF (CSLAT(I) .EQ. 0.0 .AND. CSLON(I) .EQ. 0.0) THEN
          DIST=1000.0
          GO TO 323
        ENDIF

C USING SPHERICAL COORDINATES, COMPUTE THE DISTANCE IN NAUTICAL MILES
C BETWEEN THE LIGHTNING STRIKE AND THE CENTROID

        ERAD = POLERAD + (DIFF*(COS(2.0*LILAT*DEG2RAD)+1)/2.0)
        A = CSLAT(I) - LILAT
        B = CSLON(I) - LILON
        C = ACOS((COSD(A)*COSD(B)))
        DIST = ERAD * C * 0.5399568

        DIST=(INT(DIST*10000000.0+0.7))/10000000.0
        WRITE(*,33)I,DIST,CSLAT(I),CSLON(I),LILAT,LILON,CMXZ(I),CHMXZ(I)
33        FORMAT(I3,1X,F12.8,1X,F7.4,1X,F9.4,1X,F7.3,1X,F8.3,1X,F8.3,
     $          1X,F8.3)

C USE 1000.0 AS A BASIC THRESHOLD FOR THE INITIAL DISTANCE

        IF(DIST .LT. LDIST .OR. LDIST .NE. 1000.0) THEN
          LDIST=DIST
        ENDIF

C NOW KEEP THE TWO CLOSEST DISTANCES, ALONG WITH ALL THE PERTINENT
C INFORMATION

        IF (LDIST .LT. IBDIST .AND. LDIST .LE. IADIST) THEN
          IBDIST=IADIST
          IADIST=LDIST
          IBLMON=IALMON
```

```
    IALMON=LMON
    IBLDAY=IALDAY
    IALDAY=LDAY
    IBLHR=IALHR
    IALHR=LHR
    IBLMIN=IALMIN
    IALMIN=LMIN
    IBLSEC=IALSEC
    IASEC=LSEC
    IBI=IAI
    IAI=I
    IBCSLAT=IACSLAT
    IACSLAT=CSLAT(I)
    IBCSLON=IACSLON
    IACSLON=CSLON(I)
    IBCSAZ=IACSAZ
    IACSAZ=CSAZ(I)
    IBCSRNG=IACSRNG
    IACSRNG=CSRNG(I)
    IBCMASS=IACMASS
    IACMASS=CMASS(I)
    IBCVOL=IACVOL
    IACVOL=CVOL(I)
    IBCAREA=IACAREA
    IACAREA=CAREA(I)
    IBCSDIR=IACSDIR
    IACSDIR=CSDIR(I)
    IBCSSPD=IACSSPD
    IACSSPD=CSSPD(I)
    IBCBOT=IACBOT
    IACBOT=CBOT(I)
    IBCTOP=IACTOP
    IACTOP=CTOP(I)
    IBCMXZ=IACMXZ
    IACMXZ=CMXZ(I)
    IBCHMXZ=IACHMXZ
    IACHMXZ=CHMXZ(I)
    GO TO 323
ENDIF
IF(LDIST .LT. IBDIST) THEN
    IBDIST=LDIST
    IBLMON=LMON
    IBLDAY=LDAY
    IBLHR=LHR
    IBLMIN=LMIN
    IBLSEC=LSEC
    IBI=I
    IBCSLAT=CSLAT(I)
    IBCSLON=CSLON(I)
    IBCSAZ=CSAZ(I)
    IBCSRNG=CSRNG(I)
    IBCMASS=CMASS(I)
    IBCVOL=CVOL(I)
    IBCAREA=CAREA(I)
    IBCSDIR=CSDIR(I)
    IBCSSPD=CSSPD(I)
    IBCBOT=CBOT(I)
    IBCTOP=CTOP(I)
```

```
          IBCMXZ=CMXZ(I)
          IBCHMXZ=CHMXZ(I)
        ENDIF
323   ENDDO

C NOW COMPUTE THE DISTANCE FROM THE EDGE OF THE STORM TO THE LIGHTNING
C STRIKE IN NAUTICAL MILES, IF THE AREA OF THE STORM IS GIVEN

      IF (IACAREA .EQ. 0.0) THEN
        IAAREADIST = 0.0
        GO TO 89
      ENDIF
      IBCSRAD = SQRT(IBCAREA/PI)
      IBAREADIST = IBDIST-IBCSRAD
      IACSRAD = SQRT(IACAREA/PI)
      IAAREADIST = IADIST-IACSRAD
89    CONTINUE

C NOW COMPUTE THE AZIMUTH ANGLE FROM THE MOTION ON THE CENTROID TO THE
C LIGHTNING STRIKE, IF THE SPEED AND DIRECTION OF THE CENTROID IS
C AVALIABLE

      IF (IACSDIR .NE. 999.0) THEN
        CALL  MOVEMENT (IACSLAT,IACSLON,LILAT,LILON,IACSDIR,CAZ)
      ELSE
        CAZ = 0.0
      ENDIF

C WRITE THE INFORMATION TO A FILE

      IF(LDIST .NE. 1000.0) THEN
        WRITE(12,41)IBI,IBLMON,IBLDAY,IBLHR,IBLMIN,
     $      IBDIST,IBAREADIST,IBCSLAT,IBCSLON,LILAT,LILON,IBCSAZ,
     $      IBCSRNG,LIAZ,LIRNG,IBCSDIR,IBCSSPD,IBCMASS,IBCVOL,
     $      IBCAREA,IBCBOT,IBCTOP,IBCMXZ,IBCHMXZ
41      FORMAT(I3,1X,I1,3I2,1X,2F9.5,F8.4,F10.4,F7.3,F9.3,2F6.1,
     $      2F8.3,2F6.1,2F6.0,
     $      F5.1,2F5.1,F4.0,F5.1)
        WRITE(11,42)IAI,IALMON,IALDAY,IALHR,IALMIN,
     $      IADIST,IAAREADIST,IACSLAT,IACSLON,LILAT,LILON,IACSAZ,
     $      IACSRNG,LIAZ,LIRNG,IACSDIR,IACSSPD,CAZ,IACMASS,IACVOL,
     $      IACAREA,IACBOT,IACTOP,IACMXZ,IACHMXZ
42      FORMAT(I3,1X,I1,3I2,1X,2F9.5,F8.4,F10.4,F7.3,F9.3,2F6.1,
     $      2F8.3,2F6.1,F8.3,2F6.0,
     $      F5.1,2F5.1,F4.0,F5.1)

      ENDIF
      END

      SUBROUTINE INTERP (LILAT,LILON,LIAZ,LIRNG,
     $    IOSLAT,IOSLON,OSAZ,OSRNG,LDAY,
     $    LMON,LHR,LMIN,LSEC,OSDIR,OSSPD,OMASS,OVOL,OAREA,
     $    OBOT,OTOP,OMXZ,OHMXZ)

C THIS SUBROUTINE CALCULATES THE DISTANCE FROM THE LIGHTNING STRIKE TO
C THE CENTROID FOR EACH CENTROID, THEN KEEPS C THE CLOSEST 2 DISTANCES.
C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
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C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.
C THIS SUBROUTINE IS GOOD FOR INTPEROLATED CENTROIDS ONLY
C VARIABLES:

      REAL LILAT,LILON,IOSLAT(100),IOSLON(100)
      REAL DIST,OSAZ(100),OSRNG(100),OBOT(100),OTOP(100),OMXZ(100)
      REAL OHMXZ(100),SQRT,LIAZ,LIRNG
      REAL OSDIR(100),OSSPD(100),OMASS(100),OVOL(100)
      REAL OAREA(100),LDIST,IBDIST,IADIST
      REAL IAOSDIR,IBOSDIR,IAOSSPD,IBOSSPD,IAOMASS,IBOMASS
      REAL IAOVOL,IBOVOL,PI,IAIOSLAT,IBIOSLON,IAIOSLON,IBIOSLAT
      REAL IAOSAZ,IBOSAZ,IAOSRNG,IBOSRNG
      REAL IAOTOP,IBOTOP,IAOBOT,IBOBOT,IAOMXZ,IBOMXZ,IAOHMXZ
      REAL IBOHMXZ,IAOAREA,IBOAREA,IBOSRAD,IBAREADIST,IAOSRAD
      REAL IAAREADIST
      REAL ERAD,POLERAD,DIFF
      DOUBLE PRECISION A,B,C,DEG2RAD
      INTEGER LMON,LDAY,LHR,LMIN,IALMON,IBLMON,IALDAY,IBLDAY
      INTEGER IALHR,IBLHR,IALMIN,IBLMIN,LSEC,IALSEC,IBLSEC
      PARAMETER(R=6378.0)
      POLERAD = 6356.912
      DIFF = 21.476
      DEG2RAD = 0.0174532925
      PI=ATAN(1.0)*4.0
      LDIST=1000.0

C SET INITIAL DISTANCES AT 50.0 AND 70.0 NM

      IADIST=50.0
      IBDIST=70.0

      DO I=1,100

C FIRST ZERO OUT ALL LATITUDES AND LONGITUDES WITHOUT DATA

        IF (IOSLAT(I) .EQ. 0.0 .AND. IOSLON(I) .EQ. 0.0) THEN
          DIST=1000.0
          GO TO 323
        ENDIF

C USING SPHERICAL COORDINATES, COMPUTE THE DISTANCE IN NAUTICAL MILES
C BETWEEN THE LIGHTNING STRIKE AND THE CENTROID

        ERAD = POLERAD + (DIFF*(COS(2.0*LILAT*DEG2RAD)+1)/2.0)
        A = IOSLAT(I) - LILAT
        B = IOSLON(I) - LILON
        C = ACOS((COSD(A)*COSD(B)))
        DIST = ERAD * C * 0.5399568
        DIST=(INT(DIST*10000000.0+0.7))/10000000.0

C USE 1000.0 AS A BASIC THRESHOLD FOR THE INITIAL DISTANCE

        IF(DIST .LT. LDIST .OR. LDIST .NE. 1000.0) THEN
          LDIST=DIST
        ENDIF

C NOW KEEP THE TWO CLOSEST DISTANCES, ALONG WITH ALL THE PERTINENT
```

```
C INFORMATION

        IF (LDIST .LT. IBDIST .AND. LDIST .LE. IADIST) THEN
          IBDIST=IADIST
          IADIST=LDIST
          IBLMON=IALMON
          IALMON=LMON
          IBLDAY=IALDAY
          IALDAY=LDAY
          IBLHR=IALHR
          IALHR=LHR
          IBLMIN=IALMIN
          IALMIN=LMIN
          IBLSEC=IALSEC
          IASEC=LSEC
          IBI=IAI
          IAI=I
          IBIOSLAT=IAIOSLAT
          IAIOSLAT=IOSLAT(I)
          IBIOSLON=IAIOSLON
          IAIOSLON=IOSLON(I)
          IBOSAZ=IAOSAZ
          IAOSAZ=OSAZ(I)
          IBOSRNG=IAOSRNG
          IAOSRNG=OSRNG(I)
          IBOMASS=IAOMASS
          IAOMASS=OMASS(I)
          IBOVOL=IAOVOL
          IAOVOL=OVOL(I)
          IBOAREA=IAOAREA
          IAOAREA=OAREA(I)
          IBOSDIR=IAOSDIR
          IAOSDIR=OSDIR(I)
          IBOSSPD=IAOSSPD
          IAOSSPD=OSSPD(I)
          IBOBOT=IAOBOT
          IAOBOT=OBOT(I)
          IBOTOP=IAOTOP
          IAOTOP=OTOP(I)
          IBOMXZ=IAOMXZ
          IAOMXZ=OMXZ(I)
          IBOHMXZ=IAOHMXZ
          IAOHMXZ=OHMXZ(I)
          GO TO 323
        ENDIF
        IF(LDIST .LT. IBDIST) THEN
          IBDIST=LDIST
          IBLMON=LMON
          IBLDAY=LDAY
          IBLHR=LHR
          IBLMIN=LMIN
          IBLSEC=LSEC
          IBI=I
          IBIOSLAT=IOSLAT(I)
          IBIOSLON=IOSLON(I)
          IBOSAZ=OSAZ(I)
          IBOSRNG=OSRNG(I)
          IBOMASS=OMASS(I)
```

```
          IBOVOL=OVOL(I)
          IBOAREA=OAREA(I)
          IBOSDIR=OSDIR(I)
          IBOSSPD=OSSPD(I)
          IBOBOT=OBOT(I)
          IBOTOP=OTOP(I)
          IBOMXZ=OMXZ(I)
          IBOHMXZ=OHMXZ(I)
        ENDIF
323   ENDDO

C NOW COMPUTE THE DISTANCE FROM THE EDGE OF THE STORM TO THE LIGHTNING
C STRIKE IN NAUTICAL MILES, IF THE AREA OF THE STORM IS GIVEN

      IF (IAOAREA .EQ. 0.0) THEN
        IAAREADIST = 0.0
        GO TO 89
      ENDIF
      IBOSRAD = SQRT(IBOAREA/PI)
      IBAREADIST = IBDIST-IBOSRAD
      IAOSRAD = SQRT(IAOAREA/PI)
      IAAREADIST = IADIST-IAOSRAD
89    CONTINUE

C NOW COMPUTE THE AZIMUTH ANGLE FROM THE MOTION ON THE CENTROID TO THE
C LIGHTNING STRIKE, IF THE SPEED AND DIRECTION OF THE CENTROID IS
C AVALIABLE

      IF (IAOSDIR .NE. 999.0) THEN
        CALL  MOVE  (IAIOSLAT,IAIOSLON,LILAT,LILON,IAOSDIR,CAZ)
      ELSE
        CAZ = 0.0
      ENDIF

C WRITE THE INFORMATION TO A FILE

      IF(LDIST .NE. 1000.0) THEN

        WRITE(12,41)IBI,IBLMON,IBLDAY,IBLHR,IBLMIN,
     $        IBDIST,IBAREADIST,IBIOSLAT,IBIOSLON,LILAT,LILON,IBOSAZ,
     $        IBOSRNG,LIAZ,LIRNG,
     $        IBOSDIR,IBOSSPD,IBOMASS,IBOVOL,
     $        IBOAREA,IBOBOT,IBOTOP,IBOMXZ,IBOHMXZ
41          FORMAT(I3,1X,I1,3I2,1X,2F9.5,F8.4,F10.4,F7.3,F9.3,2F6.1,
     $        2F8.3,2F6.1,2F6.0,
     $        F5.1,2F5.1,F4.0,F5.1)

        WRITE(11,42)IAI,IALMON,IALDAY,IALHR,IALMIN,
     $        IADIST,IAAREADIST,IAIOSLAT,IAIOSLON,LILAT,LILON,IAOSAZ,
     $        IAOSRNG,LIAZ,LIRNG,IAOSDIR,IAOSSPD,CAZ,IAOMASS,IAOVOL,
     $        IAOAREA,IAOBOT,IAOTOP,IAOMXZ,IAOHMXZ
42          FORMAT(I3,1X,I1,3I2,1X,2F9.5,F8.4,F10.4,F7.3,F9.3,2F6.1,
     $        2F8.3,2F6.1,F8.3,2F6.0,
     $        F5.1,2F5.1,F4.0,F5.1)
      ENDIF
      END

      SUBROUTINE LILATLON (LIAZ,LIRNG,LILAT,LILON,RDALAT,RDALON)
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C THIS SUBROUTINE CONVERTS LIGHTNING LATITUDE AND LONGITUDE TO AZIMUTH
C AND RANGE FROM THE RDA
C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.
C VARIABLES:

      REAL LIRNG,LIAZ,LILAT,LILON
      REAL RDALAT,RDALON,POLERAD,ERAD,DIFF
      DOUBLE PRECISION DEG2RAD,KM2DEG,RAD2DEG
      DOUBLE PRECISION A,B,C,S

C MUST CONVERT NEXRAD ANGLE TO SCIENTIFIC ANGLE
C PI/180 = 0.01745
C MUST CONVERT KM TO DEGREES OF LATITUDE
C 111.195 KM = 1° LATITUDE
C POLERAD IS THE RADIUS OR THE EARTH AT THE NORTH POLE
C DIFF IS THE DIFFERENCE OF THE RADIUS OF THE EARTH BETWEEN THE EQUATOR
C AND THE POLE

      RAD2DEG = 57.296
      DEG2RAD = 0.0174532925
      KM2DEG  = 111.120
      POLERAD = 6356.912
      DIFF    = 21.476

C NOW WITH LAT/LON, CONVERT TO AZIMUTH/RANGE
C USING THE SPHERICAL RIGHT TRIANGLE:  A, B, C BEING THE ANGLES OF
C THE RIGHT TRIANGLE
C ERAD IS THE RADIUS OF THE EARTH AT THE LATITUDE OF THE RDA

      ERAD = POLERAD +( DIFF*( COS(2.0*RDALAT*DEG2RAD)+1)/2.0)
      A = ( LILAT - RDALAT ) * DEG2RAD
      B = ( LILON - RDALON ) * DEG2RAD
      C = ACOS ( COS(A)*COS(B) )
      S = 0.5 * ( A + B + C )
      IF( ABS(S) .LE. 0.0000001) S = 0.0
      IF (A .EQ. 0.0) THEN
        IF (B .GT. 0.0) THEN
          LIAZ = 90.0
        ELSE
          LIAZ = 270.0
        ENDIF
      ELSE
        LIAZ=2.0*ACOS(SQRT((SIN(S)*SIN((S-B)))/(SIN(A)*SIN(C))))*RAD2DEG
      IF (B .LE. 0.0) LIAZ = 360.0 - LIAZ
      ENDIF
      LIRNG = ERAD * C
      END

      SUBROUTINE CLATLON (OSAZ,OSRNG,IOSLAT,IOSLON,RDALAT,RDALON)

C THIS SUBROUTING CONVERTS INTERPOLATED LATITUDE AND LONGITUDE TO
C AZIMUTH AND RANGE FROM THE RDA
C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
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C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.
C VARIABLES:

      REAL OSRNG(100),OSAZ(100),IOSLAT(100),IOSLON(100)
      REAL RDALAT,RDALON,POLERAD,ERAD,DIFF
      DOUBLE PRECISION DEG2RAD,KM2DEG,RAD2DEG
      DOUBLE PRECISION A(100),B(100),C(100),S(100)

C MUST CONVERT NEXRAD ANGLE TO SCIENTIFIC ANGLE
C PI/180 = 0.01745
C MUST CONVERT KM TO DEGREES OF LATITUDE
C 111.195 KM = 1° LATITUDE
C POLERAD IS THE RADIUS OR THE EARTH AT THE NORTH POLE
C DIFF IS THE DIFFERENCE OF THE RADIUS OF THE EARTH BETWEEN THE EQUATOR
C AND THE POLE

      RAD2DEG = 57.296
      DEG2RAD = 0.0174532925
      KM2DEG  = 111.120
      POLERAD = 6356.912
      DIFF    = 21.476

C NOW WITH LAT/LON, CONVERT TO AZIMUTH/RANGE
C USING THE SPHERICAL RIGHT TRIANGLE:  A, B, C BEING THE ANGLES OF
C THE RIGHT TRIANGLE
C ERAD IS THE RADIUS OF THE EARTH AT THE LATITUDE OF THE RDA

      DO I=1,100
        ERAD = POLERAD +( DIFF*( COS(2.0*RDALAT*DEG2RAD)+1)/2.0)
        A(I) = ( IOSLAT(I) - RDALAT ) * DEG2RAD
        B(I) = ( IOSLON(I) - RDALON ) * DEG2RAD
        C(I) = ACOS ( COS(A(I))*COS(B(I)) )
        S(I) = 0.5 * ( A(I) + B(I) + C(I) )
        IF( ABS(S(I)) .LE. 0.0000001) S(I) = 0.0
          IF (A(I) .EQ. 0.0) THEN
            IF (B(I) .GT. 0.0) THEN
              OSAZ(I) = 90.0
            ELSE
              OSAZ(I) = 270.0
            ENDIF
          ELSE
        OSAZ(I)=2.0*ACOS(SQRT((SIN(S(I))*SIN((S(I)-B(I))))/
     $        (SIN(A(I))*SIN(C(I)))))*RAD2DEG
        IF (B(I) .LE. 0.0) OSAZ(I) = 360.0 - OSAZ(I)
        ENDIF

        OSRNG(I) = ERAD * C(I)
      ENDDO
      END

      SUBROUTINE MOVEMENT (IACSLAT,IACSLON,
     $   LILAT,LILON,IACSDIR,CAZ)

C THIS SUBROUTINE COMPUTES THE AZIMUTH ANGLE FROM THE STORM CELL TO THE
C LIGHTNING STRIKE.  THEN THE AZIMUTH ANGLE FROM THE STORM CELL
C DIRECTION OF MOTION TO THE LIGHTNING STRIKE IS CALCULATED.
C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
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C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.
C THIS SUBROUTINE IS GOOD FOR NON-INTERPOLATED CENTROIDS ONLY
C VARIABLES:

      REAL LIRNG,LIAZ,LILAT,LILON,IACSLAT,IACSLON,IACSDIR
      REAL RDALAT,RDALON,POLERAD,ERAD,DIFF,DIFF
      REAL PTONE,PTTWO,PTTHREE,PTFOUR,CAZ,CIACSDIR
      DOUBLE PRECISION DEG2RAD,KM2DEG,RAD2DEG
      DOUBLE PRECISION A,B,C,S

C FIRST COMPUTE THE AZIMUTH ANGLE FROM THE STORM CELL TO THE LIGHTNING
C STRIKE
C MUST CONVERT NEXRAD ANGLE TO SCIENTIFIC ANGLE
C PI/180 = 0.01745
C MUST CONVERT KM TO DEGREES OF LATITUDE
C 111.195 KM = 1° LATITUDE
C POLERAD IS THE RADIUS OR THE EARTH AT THE NORTH POLE
C DIFF IS THE DIFFERENCE OF THE RADIUS OF THE EARTH BETWEEN THE EQUATOR
C AND THE POLE

      RAD2DEG = 57.296
      DEG2RAD = 0.0174532925
      KM2DEG  = 111.120
      POLERAD = 6356.912
      DIFF    = 21.476

C USE THE LATITUDE AND LONGITUDE OF THE LIGHTNING STRIKE

      RDALAT=IACSLAT
      RDALON=IACSLON


C NOW WITH LAT/LON, CONVERT TO AZIMUTH/RANGE
C USING THE SPHERICAL RIGHT TRIANGLE:  A, B, C BEING THE ANGLES OF
C THE RIGHT TRIANGLE; AA AND BB ARE THE SIDES OF THE RIGHT TRIANGLE
C ERAD IS THE RADIUS OF THE EARTH AT THE LATITUDE OF THE RDA

      ERAD = POLERAD +( DIFF*( COS(2.0*RDALAT*DEG2RAD)+1)/2.0)
      A = ( LILAT - RDALAT ) * DEG2RAD
      B = ( LILON - RDALON ) * DEG2RAD
      C = ACOS ( COS(A)*COS(B) )
      S = 0.5 * ( A + B + C )
      IF( ABS(S) .LE. 0.0000001) S = 0.0
        IF (A .EQ. 0.0) THEN
          IF (B .GT. 0.0) THEN
            LIAZ = 90.0
          ELSE
            LIAZ = 270.0
          ENDIF
        ELSE
      LIAZ=2.0*ACOS(SQRT((SIN(S)*SIN((S-B)))/(SIN(A)*SIN(C))))*RAD2DEG
      IF (B .LE. 0.0) LIAZ = 360.0 - LIAZ
      ENDIF
      LIRNG = ERAD * C

C NOW THAT WE HAVE THE AZIMUTH AND RANGE FROM THE STORM CENTER TO THE
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C LIGHTNING STRIKE, THE AZIMUTH ANGLE BETWEEN THE STORM MOTION AND THE
C LIGHTNING STIKE IS THEN COMPUTED.
C FIRST ADJUST THE DIRECTION OF MOTION OF THE STORM CELL

      IF (IACSDIR .GT. 180.0) THEN
        CIACSDIR = IACSDIR - 180.0
      ELSE
        CIACSDIR = IACSDIR + 180.0
      ENDIF

C NOW DETERMINE THE QUADRANT THE STORM MOTION IS IN
C AND TRANSFORM COORDINATE SYSTEMS WITH THE DIRECTION OF STORM MOTION
C BEING 0°

      IF (CIACSDIR .LT. 270.0) THEN
        GO TO 111
      ELSE

C QUADRANT 2

        PTONE = CIACSDIR
        PTTWO = (CIACSDIR+90.0)-360.0
        PTTHREE = (CIACSDIR+180.0)-360.0
        PTFOUR = (CIACSDIR+270.0)-360.0
        GO TO 223
      ENDIF
111   IF (CIACSDIR .LT. 180.0) THEN
        GO TO 112
      ELSE

C QUADRANT 3

        PTONE = CIACSDIR
        PTTWO = CIACSDIR+90.0
        PTTHREE = (CIACSDIR+180.0)-360.0
        PTFOUR = (CIACSDIR+270.0)-360.0
        GO TO 224
      ENDIF
112   IF (CIACSDIR .LT. 90.0) THEN
        GO TO 113
      ELSE

C QUADRANT 4

        PTONE = CIACSDIR
        PTTWO = CIACSDIR+90.0
        PTTHREE = CIACSDIR+180.0
        PTFOUR = (CIACSDIR+270.0)-360.0
        GO TO 225
      ENDIF

C QUADRANT 1

113     PTONE = CIACSDIR
        PTTWO = CIACSDIR+90.0
        PTTHREE = CIACSDIR+180.0
        PTFOUR = CIACSDIR+270.0
        GO TO 222
```

```
C NOW DETERMINE THE QUADRANT OF THE LIGHTNING STRIKE AND COMPUTE THE
C AZIMUTH ANGLE BETWEEN THE STORM MOTION AND LIGHTNING STRIKE

222   IF (LIAZ .GE. PTONE .AND. LIAZ .LT. PTTWO) THEN

C QUADRANT 1

        CAZ = ABS(LIAZ - PTONE)
        GO TO 334
      ELSE
        GO TO 115
      ENDIF
115   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. PTTHREE) THEN

C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
      ELSE
        GO TO  116
      ENDIF
116   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. PTFOUR) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        GO TO 117
      ENDIF
117   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LE. 360.0) THEN

C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ELSE
        IF (LIAZ .GT. 0.0 .AND. LIAZ .LT. PTONE) THEN
          CAZ = 360.0 - (PTONE - LIAZ)
          GO TO 334
        ENDIF
      ENDIF
223    IF (LIAZ .GE. PTONE .AND. LIAZ .LE. 360.0) THEN

C QUADRANT 1

        CAZ = ABS(LIAZ - PTONE)
        GO TO 334
       ELSE
        IF (LIAZ .GT. 0.0 .AND. LIAZ .LT. PTTWO) THEN
          CAZ = (360.0 - PTONE) + LIAZ
          GO TO 334
        ELSE
          GO TO 215
        ENDIF
       ENDIF
215   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. PTTHREE) THEN
```

```
C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
      ELSE
        GO TO  216
      ENDIF
216   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. PTFOUR) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        GO TO 217
      ENDIF
217   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LT. PTONE) THEN

C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ENDIF
224   IF (LIAZ .GE. PTONE .AND. LIAZ .LT. PTTWO) THEN

C QUADRANT 1

        CAZ = ABS(LIAZ - PTONE)
        GO TO 334
      ELSE
        GO TO 315
      ENDIF
315   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. 360.0) THEN

C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
      ELSE
        IF (LIAZ .GT. 0.0 .AND. LIAZ .LT. PTTHREE) THEN
          CAZ = (360.0 - PTTWO) + LIAZ + 90.0
          GO TO 334
        ELSE
          GO TO 316
        ENDIF
      ENDIF
316   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. PTFOUR) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        GO TO 317
      ENDIF
317   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LT. PTONE) THEN
```

```
C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ENDIF
225   IF (LIAZ .GE. PTONE .AND. LIAZ .LT. PTTWO) THEN

C QUADRANT 1

        CAZ = ABS(LIAZ - PTONE)
        GO TO 334
      ELSE
        GO TO 415
      ENDIF
415   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. PTTHREE) THEN

C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
      ELSE
        GO TO 416
      ENDIF
416   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. 360.0) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        IF (LIAZ .GT. 0.0 .AND. LIAZ .LT. PTFOUR) THEN
          CAZ = (360.0 - PTTHREE) + LIAZ + 180.0
          GO TO 334
        ELSE
          GO TO 417
        ENDIF
      ENDIF
417   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LT. PTONE) THEN

C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ENDIF
334   CONTINUE
      END

      SUBROUTINE MOVE (IAIOSLAT,IAIOSLON,LILAT,LILON,IAOSDIR,CAZ)

C THIS SUBROUTINE COMPUTES THE AZIMUTH ANGLE FROM THE STORM CELL TO THE
C LIGHTNING STRIKE.  THEN THE AZIMUTH ANGLE FROM THE STORM CELL
C DIRECTION OF MOTION TO THE LIGHTNING STRIKE IS CALCULATED.
C THIS COMPUTATION USES SPHERICAL COORDINATES AND THE SPHERICAL RIGHT
C TRIANGLE.  THIS DERIVATION IS TAKEN FROM THE HANDBOOK OF MATHEMATICAL,
C SCIENTIFIC, AND ENGINEERING FORMULAS, TABLES, FUNCTIONS, GRAPHS,
C TRANSFORMATIONS, FOGIEL, 1984.
C THIS SUBROUTINE IS GOOD FOR INTERPOLATED CENTROIDS ONLY
C VARIABLES:
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      REAL LIRNG,LIAZ,LILAT,LILON,IAIOSLAT,IAIOSLON,IAOSDIR
      REAL RDALAT,RDALON,POLERAD,ERAD,DIFF,DIFF
      REAL PTONE,PTTWO,PTTHREE,PTFOUR,CAZ,CIAOSDIR
      DOUBLE PRECISION DEG2RAD,KM2DEG,RAD2DEG
      DOUBLE PRECISION A,B,C,S

C FIRST COMPUTE THE AZIMUTH ANGLE FROM THE STORM CELL TO THE LIGHTNING
C STRIKE
C MUST CONVERT NEXRAD ANGLE TO SCIENTIFIC ANGLE
C PI/180 = 0.01745
C MUST CONVERT KM TO DEGREES OF LATITUDE
C 111.195 KM = 1° LATITUDE
C POLERAD IS THE RADIUS OR THE EARTH AT THE NORTH POLE
C DIFF IS THE DIFFERENCE OF THE RADIUS OF THE EARTH BETWEEN THE EQUATOR
C AND THE POLE

      RAD2DEG = 57.296
      DEG2RAD = 0.0174532925
      KM2DEG  = 111.120
      POLERAD = 6356.912
      DIFF    = 21.476

C USE THE LATITUDE AND LONGITUDE OF THE LIGHTNING STRIKE

      RDALAT=IAIOSLAT
      RDALON=IAIOSLON

C NOW WITH LAT/LON, CONVERT TO AZIMUTH/RANGE
C NOW WITH LAT/LON, CONVERT TO AZIMUTH/RANGE
C USING THE SPHERICAL RIGHT TRIANGLE:  A, B, C BEING THE ANGLES OF
C THE RIGHT TRIANGLE; AA AND BB ARE THE SIDES OF THE RIGHT TRIANGLE
C ERAD IS THE RADIUS OF THE EARTH AT THE LATITUDE OF THE RDA

      ERAD = POLERAD +( DIFF*( COS(2.0*RDALAT*DEG2RAD)+1)/2.0)
      A = ( LILAT - RDALAT ) * DEG2RAD
      B = ( LILON - RDALON ) * DEG2RAD
      C = ACOS  ( COS(A)*COS(B) )
      S = 0.5 * ( A + B + C )
      IF( ABS(S) .LE. 0.0000001) S = 0.0
        IF (A .EQ. 0.0) THEN
          IF (B .GT. 0.0) THEN
            LIAZ = 90.0
          ELSE
            LIAZ = 270.0
          ENDIF
        ELSE
      LIAZ=2.0*ACOS(SQRT((SIN(S)*SIN((S-B)))/(SIN(A)*SIN(C))))*RAD2DEG
      IF (B .LE. 0.0) LIAZ = 360.0 - LIAZ
      ENDIF
      LIRNG = ERAD * C

C NOW THAT WE HAVE THE AZIMUTH AND RANGE FROM THE STORM CENTER TO THE
C LIGHTNING STRIKE, THE AZIMUTH ANGLE BETWEEN THE STORM MOTION AND THE
C LIGHTNING STIKE IS THEN COMPUTED.
C FIRST ADJUST THE DIRECTION OF MOTION OF THE STORM CELL

      IF (IAOSDIR .GT. 180.0) THEN
```

```
        CIAOSDIR = IAOSDIR - 180.0
      ELSE
        CIAOSDIR = IAOSDIR + 180.0
      ENDIF

C NOW DETERMINE THE QUADRANT THE STORM MOTION IS IN
C AND TRANSFORM COORDINATE SYSTEMS WITH THE DIRECTION OF STORM MOTION
C BEING 0°

      IF (CIAOSDIR .LT. 270.0) THEN
        GO TO 111
      ELSE

C QUADRANT 2

        PTONE = CIAOSDIR
        PTTWO = (CIAOSDIR+90.0)-360.0
        PTTHREE = (CIAOSDIR+180.0)-360.0
        PTFOUR = (CIAOSDIR+270.0)-360.0
        GO TO 223
      ENDIF
111   IF (CIAOSDIR .LT. 180.0) THEN
        GO TO 112
      ELSE

C QUADRANT 3

        PTONE = CIAOSDIR
        PTTWO = CIAOSDIR+90.0
        PTTHREE = (CIAOSDIR+180.0)-360.0
        PTFOUR = (CIAOSDIR+270.0)-360.0
        GO TO 224
      ENDIF
112   IF (CIAOSDIR .LT. 90.0) THEN
        GO TO 113
      ELSE

C QUADRANT 4

        PTONE = CIAOSDIR
        PTTWO = CIAOSDIR+90.0
        PTTHREE = CIAOSDIR+180.0
        PTFOUR = (CIAOSDIR+270.0)-360.0
        GO TO 225
      ENDIF

C QUADRANT 1

113     PTONE = CIAOSDIR
        PTTWO = CIAOSDIR+90.0
        PTTHREE = CIAOSDIR+180.0
        PTFOUR = CIAOSDIR+270.0
        GO TO 222

C NOW DETERMINE THE QUADRANT OF THE LIGHTNING STRIKE AND COMPUTE THE
C AZIMUTH ANGLE BETWEEN THE STORM MOTION AND LIGHTNING STRIKE

222   IF (LIAZ .GE. PTONE .AND. LIAZ .LT. PTTWO) THEN
```

```
C QUADRANT 1

        CAZ = ABS(LIAZ - PTONE)
        GO TO 334
      ELSE
        GO TO 115
      ENDIF
115   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. PTTHREE) THEN

C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
      ELSE
        GO TO  116
      ENDIF
116   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. PTFOUR) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        GO TO 117
      ENDIF
117   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LE. 360.0) THEN

C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ELSE
        IF (LIAZ .GT. 0.0 .AND. LIAZ .LT. PTONE) THEN
          CAZ = 360.0 - (PTONE - LIAZ)
          GO TO 334
        ENDIF
      ENDIF
223    IF (LIAZ .GE. PTONE .AND. LIAZ .LE. 360.0) THEN

C QUADRANT 1

         CAZ = ABS(LIAZ - PTONE)
         GO TO 334
       ELSE
         IF (LIAZ .GE. 0.0 .AND. LIAZ .LT. PTTWO) THEN
           CAZ = (360.0 - PTONE) + LIAZ
           GO TO 334
         ELSE
           GO TO 215
         ENDIF
       ENDIF
215   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. PTTHREE) THEN

C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
```

```
      ELSE
        GO TO  216
      ENDIF
216   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. PTFOUR) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        GO TO 217
      ENDIF
217   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LT. PTONE) THEN

C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ENDIF
224   IF (LIAZ .GE. PTONE .AND. LIAZ .LT. PTTWO) THEN

C QUADRANT 1

        CAZ = ABS(LIAZ - PTONE)
        GO TO 334
      ELSE
        GO TO 315
      ENDIF
      315   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. 360.0) THEN

C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
      ELSE
        IF (LIAZ .GT. 0.0 .AND. LIAZ .LT. PTTHREE) THEN
          CAZ = (360.0 - PTTWO) + LIAZ + 90.0
          GO TO 334
        ELSE
          GO TO 316
        ENDIF
      ENDIF
316   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. PTFOUR) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        GO TO 317
      ENDIF
317   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LT. PTONE) THEN

C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ENDIF
```

```
225   IF (LIAZ .GE. PTONE .AND. LIAZ .LT. PTTWO) THEN

C QUADRANT 1

        CAZ = ABS(LIAZ - PTONE)
        GO TO 334
      ELSE
        GO TO 415
      ENDIF
415   IF (LIAZ .GE. PTTWO .AND. LIAZ .LT. PTTHREE) THEN

C QUADRANT 4

        CAZ = ABS(LIAZ - PTTWO) + 90.0
        GO TO 334
      ELSE
        GO TO 416
      ENDIF
416   IF (LIAZ .GE. PTTHREE .AND. LIAZ .LT. 360.0) THEN

C QUADRANT 3

        CAZ = ABS(LIAZ - PTTHREE) + 180.0
        GO TO 334
      ELSE
        IF (LIAZ .GT. 0.0 .AND. LIAZ .LT. PTFOUR) THEN
          CAZ = (360.0 - PTTHREE) + LIAZ + 180.0
          GO TO 334
        ELSE
          GO TO 417
        ENDIF
      ENDIF
417   IF (LIAZ .GE. PTFOUR .AND. LIAZ .LT. PTONE) THEN

C QUADRANT 2

        CAZ = (LIAZ - PTFOUR) + 270.0
        GO TO 334
      ENDIF
334   CONTINUE
      END
```

APPENDIX F

This appendix contains the top ten distributions for horizontal distances between all lightning strikes and storm centroids at each site for April and June.

SITE	RANK		DISTRIBUTION	
	APRIL	JULY	APRIL	JULY
DYX	100	95.83	Johnson SB	Log-Logistic
	88.75	94.79	Lognormal	Log-Laplace
	85	92.71	Random Walk	Log-Laplace (E)
	82.5	91.67	Log-Logistic (E)	Log-Logistic (E)
	81.25	83.33	Log-Logistic	Gamma
	80	78.13	Gamma (E)	Gamma (E)
	72.5	73.96	Gamma	Erlang (E)
	65	72.92	Lognormal	Erlang
	63.75	66.67	Weibull (E)	Lognormal
	56.25	56.25	Weibull	Weibull (E)
EVX	N/A	100	N/A	Gamma
	N/A	94.79	N/A	Log-Logistic
	N/A	81.25	N/A	Gamma (E)
	N/A	79.17	N/A	Rayleigh
	N/A	78.13	N/A	Erlang
	N/A	77.08	N/A	Log-Laplace
	N/A	77.08	N/A	Rayleigh (E)
	N/A	76.04	N/A	Log-Logistic (E)
	N/A	72.92	N/A	Log-Laplace (E)
	N/A	67.71	N/A	Weibull (E)
FDR	100	98.81	Log-Logistic	Gamma
	91.67	94.05	Gamma	Gamma (E)
	89.29	91.67	Gamma (E)	Weibull (E)
	86.9	86.9	Log-Logistic (E)	Weibull
	82.14	76.19	Erlang (E)	Log-Logistic
	75	73.81	Erlang	Erlang (E)
	75	71.43	Lognormal	Log-Logistic (E)
	64.29	69.05	Weibull	Erlang
	63.1	59.52	Random Walk	Lognormal
	58.33	53.57	Weibull (E)	Lognormal (E)

SITE	RANK		DISTRIBUTION	
	APRIL	JULY	APRIL	JULY
LIX	100	100	Log-Logistic	Gamma
	95.24	95.24	Log-Logistic (E)	Gamma (E)
	90.48	85.71	Lognormal	Weibull (E)
	82.14	82.14	Gamma (E)	Log-Logistic
	80.95	79.76	Lognormal (E)	Weibull
	76.19	76.19	Gamma	Erlang (E)
	73.81	76.19	Erlang	Log-Logistic (E)
	67.86	71.43	Random Walk	Erlang
	59.52	61.9	Weibull (E)	Lognormal
	58.33	57.14	Pearson Type 6	Lognormal (E)
MOB	100	100	Log-Logistic	Gamma
	95.24	95.24	Log-Logistic (E)	Gamma (E)
	90.48	88.1	Lognormal	Log-Logistic
	85.71	83.33	Lognormal (E)	Erlang (E)
	79.76	83.33	Pearson Type 6	Log-Logistic (E)
	77.38	77.38	Random Walk	Erlang
	71.43	71.43	Pearson Type 6 (E)	Weibull (E)
	66.67	65.48	Gamma (E)	Lognormal
	61.9	64.29	Gamma	Weibull
	57.14	57.14	Inverse Gaussian	Lognormal (E)
TLH	100	100	Log-Logistic	Gamma
	95	92.05	Log-Logistic (E)	Gamma (E)
	90	92.05	Lognormal	Weibull (E)
	81.25	84.09	Lognormal (E)	Weibull
	77.5	81.82	Gamma (E)	Log-Logistic
	76.25	71.59	Random Walk	Log-Logistic (E)
	71.25	70.45	Gamma	Rayleigh
	68.75	69.32	Pearson Type 6	Lognormal
	60	68.18	Weibull (E)	Erlang (E)
	55	56.82	Weibull	Random Walk
TLX	97.62	100	Gamma	Gamma
	96.43	95.24	Log-Logistic	Gamma (E)
	91.67	90.48	Gamma (E)	Weibull (E)
	83.33	85.71	Log-Logistic (E)	Weibull
	82.14	78.57	Erlang (E)	Log-Logistic
	72.62	71.43	Weibull (E)	Erlang (E)
	71.43	71.43	Lognormal	Log-Logistic (E)
	66.67	65.48	Weibull	Lognormal
	66.67	60.71	Erlang	Erlang
	55.95	59.52	Random Walk	Rayleigh

SITE	RANK		DISTRIBUTION	
	APRIL	JULY	APRIL	JULY
VNX	97.5	96.43	Log-Logistic	Gamma (E)
	96.25	95.24	Gamma	Gamma
	87.5	94.05	Gamma (E)	Erlang
	81.25	83.33	Log-Logistic (E)	Log-Logistic
	78.75	78.57	Erlang (E)	Lognormal
	73.75	78.57	Lognormal	Log-Logistic (E)
	71.25	72.62	Weibull (E)	Weibull (E)
	68.75	67.86	Erlang	Weibull
	65	60.71	Weibull	Lognormal (E)
	53.75	57.14	Random Walk	Random Walk

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13. ABSTRACT *(Maximum 200 words)*

On April 29, 1996, lightning struck the airfield at Hurlburt Field, FL, killing one Airmen and injuring ten others. This cloud-to-ground lightning strike hit eight minutes after a lightning advisory was canceled. At the time of the strike, thunderstorms were observed 7 to 10 miles north and south of the airfield. The incident raised questions about Air Force Weather Agency's lightning criteria. Soon after the incident, a Lightning Safety Review Panel was assembled to determine the adequacy of lightning advisories. One of the questions posed to the panel was "could an incident like Hurlburt happen again?" The review panel could not answer that question due to the lack of documented research on how far lightning can travel horizontally before striking the ground.

This thesis used the WSR-88D Algorithm Testing and Display System (WATADS) and the default parameters of the WATADS's Storm Cell Identification and Tracking (SCIT) Algorithm to identify thunderstorm centroids. Lightning strike data containing nearly 50,000 cloud-to-ground strikes was obtained through the National Climatic Data Center (NCDC). Horizontal distances were then computed between these storm centroids and cloud-to-ground lightning strikes.

This research discovered that average distances between thunderstorm centroids and lightning strikes vary with season and location. In addition, nearly 75% of all lightning strikes occurred within 10 nautical miles of thunderstorm centroids

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